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ESTUARINE HEALTH IN TASMANIA, STATUS AND INDICATORS: WATER QUALITY

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Executive summary

This report describes the results of a research project conducted under the Coast and Cleans Seas program of the Natural Heritage Trust fund. It provides a summary and assessment of water quality parameters, as indicators of estuarine health, in 22 selected Tasmanian estuaries. Information is summarised on both a State wide and individual estuary basis.

Vertical salinity stratification was seen in most estuaries and was very distinct in river estuaries, particularly the large, deep estuaries on the west coast (Arthur and Pieman) and small, east coast river estuaries (Douglas, Meredith, Browns and Catamaran). The upstream section of Ansons Bay was also highly stratified. The estuaries that were not vertically stratified were generally open, marine inlets (East Inlet, Port Sorell, Great Swanport, Little Swanport and Cloudy Bay) or shallow, low salinity estuaries (Boobyalla Inlet and Nelson Bay). Salinity differences along the length of the estuary were recorded for all the study estuaries. The greatest vertical stratification and horizontal variation was seen in the upper sections of each estuary. In 15 of the 22 estuaries, salinity ranges of over 30 ppt were recorded throughout the estuary over the 12 months of the study. As with salinity, differences in temperature and dissolved oxygen concentrations between surface and bottom waters were most evident in river estuaries. Due to vertical stratification being very distinct in river estuaries, future water quality monitoring programs should determine indicator levels from bottom water in these systems

For key water quality parameters, the baseline data were used to derive regional-specific draft indicator levels to be used in preference to ANZECC guidelines. Indicator levels were divided into four categories (low, medium, high, and very high) that may indicate differences in 'pressure' on the system. Indicator levels were referenced against the range of values recorded around the State and are based on the likelihood of exceeding these values during a single sampling event. Indicator levels may be used to trigger different management responses depending on the scale at which values are exceeded. Table 1 provides average values for each sampling occasion and the median value for the year July 1999/June 2000 of water quality parameters (surface waters) for all estuaries, by bioregion.

For all estuaries combined, turbidity ranged from 0.4 to 355 NTU with a median value of 2.6 NTU. Chlorophyll *a* concentrations ranged from 0.0 to 87.8 $\mu g\ l^{-1}$ and a median of 0.68 $\mu g\ l^{-1}$. NO_x-N and PO_4-P ranged from 0 to 1326 $\mu g\ l^{-1}$ and 0 to 197 $\mu g\ l^{-1}$, respectively, with median values of 7 and 5 $\mu g\ l^{-1}$.

For most estuaries, principal component analysis (PCA) poorly described the total variation in the data from surface waters. As such, no single parameter was clearly identified as a suitable proxy for water quality. The first or second component in PCA frequently described a positive relationship between turbidity and suspended solids, often having a negative relationship with salinity, particularly in the more degraded estuaries on the north coast.

Many estuaries on the north coast (Boags bioregion) were unhealthy, relative to other estuaries in the State, with elevated turbidity, nitrogen and phosphorus concentrations, particularly the Duck Bay and Don River estuaries. These systems need further study to quantify anthropogenic and natural sources of nutrients. Estuaries in the north-east, such as Boobyalla Inlet, Little Musselroe River and Ansons Bay, showed high nitrogen or chlorophyll concentrations and require further study to determine susceptibility to eutrophication. In comparison, estuaries in the remaining regions, were generally healthy, with indicator levels in the low to medium range. The exceptions to this were Browns and Meredith River and, on occasion, the Douglas Rivers. Very low oxygen concentrations in bottom waters associated with a salt wedge occurred in the Arthur River and Ansons Bay.

The defined sampling sites and sampling protocols used in this study for baseline data collection allow for meaningful, long-term comparison of estuarine water quality. However, ongoing assessment of estuarine health status requires the establishment of a long-term targeted monitoring program. We recommend that, as a minimum, comparative assessments are conducted at least every five years and are linked to the State of the Environment reporting cycle.

The utility of estuarine water quality data (*i.e.* nutrients and turbidity) currently collected by community groups for long-term monitoring may be limited by the detection limits of sampling equipment. Government or research organisations are most likely to have the expertise to conduct long-term monitoring and health assessment, established reporting structures and inputs to management responses.

Table 1. Average turbidity (NTU), chlorophyll *a*, NOx and PO_4 concentrations (µg l^{-1}) and yearly median value for each estuary, by bioregion and sampling event, July 1999 to June 2000

			Sample						
Bioregion	Estuary	Parameter	JA99	SO99	ND99	JF00	MA00	MJ00	median (JA99-MJ00)
Boags	Duck Bay	Turbidity	21.0	17.6	7.0	8.7	6.0	12.2	8.3
		Chlorophyll a	2.9	2.0	1.4	1.4	1.5	1.7	1.5
		NOx	289	268	165	39	93	235	127
		PO4	104	30	27	30	17	15	28
	East Inlet	Turbidity	2.1	2.8	1.1	1.9	0.9	1.7	1.7
		Chlorophyll a	0.1	0.0	4.4	0.6	0.0	0.2	0.0
		NOx	5	3	1	1	2	3	2
		PO4	20	12	8	10	11	11	11
	Black River	Turbidity	8.9	3.9	3.8	3.0	2.9	3.1	3.4
		Chlorophyll a	0.2	0.1	0.8	0.9	0.7	0.2	0.4
		NOx	95	62	48	24	48	55	57
		PO4	5	6	3	9	5	1	4
	Don River	Turbidity	50.0	9.8	125.3	no data	8.1	4.5	8.6
		Chlorophyll a	2.5	0.7	25.6	17.6	0.7	0.1	0.8
		NOx	1125	328	20	5	31	343	118
		PO4	8	4	31	11	13	8	9
	Mersey River	Turbidity	12.0	3.6	13.3	no data	6.3	3.1	5.5
		Chlorophyll a	0.8	0.3	3.1	0.9	0.7	0.2	0.5
		NOx	289	65	19	24	22	61	31
		PO4	8	8	9	15	13	10	11
	Port Sorell	Turbidity	39.9	6.6	5.4	no data	4.8	3.1	5.4
		Chlorophyll a	1.3	1.2	1.6	0.9	0.5	0.3	0.8
		NOx	217	5	0	2	4	11	4
		PO4	12	22	9	8	9	6	8
	Boobyalla Inlet	Turbidity	16.9	13.2	4.2	4.5	4.2	8.2	6.9
		Chlorophyll a	1.7	1.4	0.8	4.1	1.1	0.8	1.2
		NOx	250	277	132	72	18	158	138
		PO4	9	6	1	2	3	2	2
	Little Musselroe River	Turbidity	4.0	5.4	1.6	6.7	3.5	3.9	3.4
		Chlorophyll a	1.6	0.6	0.0	33.2	2.5	2.0	1.1
		NOx	16	24	1	2	1	13	4
		PO4	8	7	4	17	4	6	6
Freycinet	Ansons Bay	Turbidity	1.4	2.6	1.8	5.3	1.7	0.8	1.7
		Chlorophyll a	20.3	8.8	5.7	11.2	7.5	2.2	5.3
		NOx	5	4	1	14	2	3	2
		PO4	10	6	3	10	14	12	8
	Grants Lagoon	Turbidity	1.2	1.3	2.7	2.2	1.7	1.2	1.5
		Chlorophyll a	1.3	1.0	0.4	3.0	1.2	0.8	1.2
		NOx	17	3	0	1	2	38	1
		PO4	4	2	3	3	2	2	2
	Douglas River	Turbidity	8.0	1.4	1.6	2.1	1.4	2.1	1.7
		Chlorophyll a	0.1	1.0	0.7	0.0	0.3	0.0	0.0
		NOx	11	0	11	178	75	62	24
		PO4	1	2	2	3	2	8	2
	Great Swanport	Turbidity	1.7	1.5	1.6	1.5	1.4	1.8	1.4
		Chlorophyll a	0.3	0.4	0.1	0.9	0.6	1.0	0.5
		NOx	0	2	0	2	1	0	1
		PO4	6	3	2	4	5	2	3
	Meredith River	Turbidity	14.8	0.9	2.5	3.4	3.5	0.9	2.6
		Chlorophyll a	6.0	2.2	8.8	3.2	10.0	0.8	1.9
		NOx	124	6	1	56	3	6	6
		PO4	5	2	3	6	4	2	2
	Little Swanport	Turbidity	1.8	1.5	2.1	2.3	3.3	2.1	1.8
		Chlorophyll a	0.7	0.3	1.2	2.4	6.1	1.1	1.1
		NOx	3	1	0	0	0	2	0
		PO4	6	4	3	3	5	4	4
	Earlham Lagoon	Turbidity	3.7	1.8	2.0	2.1	3.0	0.9	2.0
		Chlorophyll a	0.9	0.2	0.5	0.8	0.6	0.1	0.4
		NOx	28	1	1	5	1	2	2
		PO4	9	6	6	5	6	6	6
Bruny	Browns River	Turbidity	56.0	1.8	3.9	5.0	5.1	3.1	3.2
		Chlorophyll a	2.4	0.7	2.5	7.0	9.2	4.7	2.6
		NOx	332	8	3	1	1	10	5
		PO4	8	14	25	13	42	17	16
	Cloudy Bay Lagoon	Turbidity	1.2	0.9	1.4	1.1	1.0	1.4	1.0
		Chlorophyll a	2.3	0.9	0.3	0.9	0.6	1.0	0.7
		NOx	7	4	0	2	1	13	1
		PO4	6	4	5	9	5	9	6
Davey	Catamaran River	Turbidity	3.1	1.2	1.2	2.0	1.1	2.0	1.5
		Chlorophyll a	0.0	0.6	0.5	0.1	0.1	0.0	0.0
		NOx	13	9	0	1	6	9	5
		PO4	4	7	5	5	5	4	5
	Cockle Creek	Turbidity	3.5	1.0	1.3	1.3	1.6	1.5	1.4
		Chlorophyll a	0.7	1.2	0.6	0.1	1.1	0.8	0.4
		NOx	22	5	1	1	1	7	2
		PO4	5	7	2	4	3	3	4
Franklin	Pieman River	Turbidity	2.9	9.8	1.8	1.6	4.6	2.6	2.6
		Chlorophyll a	0.0	0.0	0.0	0.1	0.2	0.0	0.0
		NOx	28	22	36	20	21	19	23
		PO4	1	0	0	2	0	0	0
	Nelson Bay River	Turbidity	6.2	10.7	5.9	4.2	1.3	3.1	5.2
		Chlorophyll a	0.0	0.1	0.0	3.4	1.5	0.0	0.0
		NOx	13	7	8	2	3	8	7
		PO4	2	1	1	8	5	2	2
	Arthur River	Turbidity	10.5	5.2	8.2	2.5	2.9	4.3	4.5
		Chlorophyll a	0.0	0.1	0.0	0.6	0.1	0.0	0.0
		NOx	39	17	10	5	9	20	13
		PO4	3	1	1	2	0	1	1

Draft (indicator levels)		low	medium	high	very high
Turbidity	NTU	0 to 4	4.1 to 10	10.1 to 20	> 20
Chlorophyll a	µ g/L	0 to 2	2.1 to 5	5.1 to 10	> 10
NOx	µ g/L	0 to 20	21 to 50	51 to 100	> 100
PO4	µ g/L	0 to 5	6 to 15	16 to 30	> 30

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1. Introduction

1.1 Physical classification

By necessity, a study of estuaries must specify which bodies of waters are to be included within the definition of 'estuary'. Globally, classification has tended towards geomorphological descriptions and three major physical classification studies of Tasmanian estuaries have been conducted. The estuarine classifications of Digby *et al.* (1998) and Heap *et al.* (2001) were both Australia-wide studies, whereas Edgar *et al.* (1999) investigated Tasmanian estuaries only.

Digby *et al*. (1998) used the Bucher & Saenger (1989) definition of estuaries, being *"semi-enclosed bodies of water and adjacent wetlands which have input from marine and tidal inundation and terrestrial runoff"*. In addition to this definition, Bucher & Saenger (1989) also identified 'enclosed marine waters' (that were distinct from estuaries). Enclosed marine waters were defined as *"bodies of water that are considered to be sufficiently enclosed as to contain environments distinct from open coasts and that, from a management point of view, are best considered as a unit",* however, if such a body also included a single estuary, then it was treated as a single unit. For Tasmania, Bucher & Saenger (1989) recognised 58 estuaries [which were then used by Digby *et. al* (1998)] and 5 enclosed marine waters.

Edgar *et al*. (1999) defined an estuary as *"a semi-enclosed or periodically closed coastal body of water in which the aquatic environment is affected by the physical and chemical characteristics of both fluvial drainage and marine systems"*. This definition included coastal lakes, lagoons and rivers upstream to the limit of tidal influence. It recognised the importance of external inputs from both marine and terrestrial environments and implied a seaward geographical limit at the opening to the sea. The definition used was more liberal than that of Bucher and Saenger (1989) and resulted in the inclusion of nearly double their number of estuaries (111 cf. 63). Edgar *et al*. (1999) included the 58 estuaries described in Bucher and Saenger (1989) but excluded the five enclosed marine waters (i.e. Robbins Passage, Norfolk Bay, Ralphs Bay, D'Entrecasteaux Channel and Recherche Bay). However, numerous smaller estuaries associated with these marine embayments were included.

Digby *et al.* (1998) classified Australian estuaries by determining biologically important physical variables that explained variation in mangrove and saltmarsh proportions. Categories were further defined by two terms, climatic zones and extreme tidal range. However, because temperate estuaries have few or no mangroves this resulted in Tasmanian estuaries being classified in the single category of 'temperate, low tide estuaries'.

Edgar *et al.* (1999) used 1:25,000 topographic map sheets, aerial photographs and the structure of the estuary mouth to initially classify Tasmanian estuaries into six geomorphological classes. These classes were:

- (i) coastal inlets; (ii) drowned river valleys; (iii) permanently-open barrier estuaries; (iv) seasonally-closed barrier estuaries; (v) river estuaries, and (vi) coastal lagoons.

Physio-chemical attributes were then used to further classify these estuaries were into nine groups. This classification was primarily reflected by the size of the estuary, the presence of any seaward barrier and tidal, salinity and rainfall characteristics (Edgar *et al.* 1999). These groups were:

- (I) barred, low salinity estuaries; (II) open estuaries; (III) marine inlets and bays; (IV) hypersaline lagoons; (V) large mesotidal river estuaries; (VI) mesotidal drowned river valley; (VII) microtidal drowned river valley; (VIII) large open microtidal; and (IX) barred river.

The majority of Tasmanian estuaries were classified as either barred, low salinity estuaries (25%), open estuaries (24%), large mesotidal river estuaries (15 %) or marine inlets and bays (14 %).

Heap *et al.* (2001) recognised 116 Tasmanian 'estuaries'; the 111 of Edgar *et al.* (1999) plus the 5 enclosed marine waters in Bucher and Saenger (1989). The estuaries were physically classified by first modelling the ratio of wave to tide energy at the mouth of the estuary, and by then including river energy into the model. This resulted in three estuarine categories;

- (i) tide dominated; (ii) wave dominated, and (iii) river dominated.

The geomorphology of each estuary was then incorporated into the model, resulting in seven sub-classes within the three energy based categories. The sub-classes were;

- (i) strandplain; (ii) tidal flat/creek; (iii) tide-dominated estuaries; (iv) wave-dominated estuaries; (v) tide-dominated deltas; (vi) wave-dominated deltas, and (vii) other (*eg*. drowned river valleys, coastal embayments and coastal lagoons)

The majority of Tasmanian estuaries were classified as being within the 'wave dominated' (67%) category and within the 'other' (53%) or 'wave-dominated estuary' (28%) sub-class.

The estuarine classification of Heap *et al.* (2001) was used to define estuarine type in the National Land and Water Resources Audits.

1.2 Importance and impacts

Estuaries are ecologically and economically important ecosystems. They can be highly productive systems offering significant habitat for fish and birds, but are often sites of high population density and industrial development. Humans commonly use estuaries as a means of disposing of urban waste (*i.e.* sewage and stormwater) and industrial waste. Agriculture and forestry within catchments has led to increases in run-off and changed flow rates. These factors result in increasing sediment and nutrient loads to rivers and, thus, into the estuaries, causing a deterioration of water quality, increased siltation and habitat loss (Saenger 1995; Edgar *et al.* 1999).

Edgar *et al.* (1994) concluded that virtually all estuaries along the east and north coasts of mainland Tasmania are badly degraded by pollution, siltation, nutrification and onshore developments. They suggested that estuarine habitats are under a greater threat from human impacts than any other marine ecosystems in Tasmania. Estuarine degradation caused by increased sediment loads, eutrophication and changed flows was identified in the Commonwealth State of the Marine Environment Report as one of the most serious marine environmental issues facing Australia (Saenger 1995). Tasmanian State of the Environment (Sustainable Development Advisory Council 1996) identified that there were major gaps in our knowledge of estuaries, such as water quality and biotic inventories. These gaps prevent the detection and early remediation of problems and limit our ability to interpret and implement State Coastal and Water Policies. The lack of data regarding estuarine systems can be largely attributed to jurisdictional boundaries; being neither freshwater nor marine they have been generally ignored.

1.3 Estuarine health and monitoring

The term 'ecosystem health' is a relatively recent addition to the ecological literature (Rapport *et al.* 1979) and refers to the "state, condition or performance of an ecosystem as defined in terms of some desired endpoint" (Rapport *et al.* 1998). By definition, it is a subjective measure; judgements of observations and measurements being made against our expectations of what an ecosystem 'should be like' and our values concerning nature. Importantly, these expectations can be anthropocentric as well as ecocentric (Fairweather 1993, Fairweather 1999).

In a review of the assessment of ecological health of Australian estuaries, Deeley and Paling (1999) identified that while it was relatively simple to define indicators that describe the status quo (*e.g.* eutrophication using nutrient or chlorophyll concentrations), it is more difficult to develop a predictive capacity. Therefore, they suggested that a range of indicators were needed to provide for assessments of current status, a measure of diagnostic precision and a robust predictive capacity ('early warning'). Although commonly measured water quality parameters could be considered as "describing the status quo", nonetheless, their measurement goes some way to fulfilling each of requirement of suitable indicators described by Deeley and Paling (1999).

Ecosystem health of estuaries and indicators of estuarine health were discussed by Fairweather (1999). He suggested that the role of an indicator is simply to document impacts so that further action can be taken. That is, the detection of change by an indicator should trigger the availability of resources for more thorough studies that aim to better understand the cause and effect of the detected impact. For an indicator to be used routinely, it must be easily collected, have a clear interpretation and involve an explicit feedback loop to management. Although Fairweather (1999) proposed a shift away from simple water quality monitoring in regard to assessing estuarine health, many water quality parameters fit the criteria of suitable indicators, in that they are easily collected and have useable outputs that are usually understood by the general public.

Recognising this, guidelines for water quality monitoring and assessment in Australia and New Zealand (ANZECC 2000) summarise that any monitoring of indicators should include:

- explicit definition of the sampling area, project objectives, a hypothesis and the sampling protocol that will support the work

- the definition of sampling sites, sampling frequency, and spatial and temporal variability that will permit an appropriate statistical method to be used
- rigorous attention to field and laboratory quality control and assurance
- incorporation of a pilot study to test the sampling protocol and refine spatial and temporal variability.

1.4 Monitoring health indicators

By definition, estuaries are highly variable systems. They are influenced by rainfall, freshwater and marine inputs, evaporation and by the ebb and flow of the tide. They can show both vertical and horizontal stratification and can be open or closed to the sea. The determination of indicators, and any subsequent monitoring using those indicators, needs to take into account this natural variability.

In the past two decades, appropriate experimental and statistical methods for detecting environmental impacts have been the source of many studies and much debate (Green 1979; Stewart-Oaten *et al.* 1986; Stewart-Oaten *et al.* 1992; Underwood 1991; etc.). While the focus of many of these papers has been the assessment of temporal and spatial changes in invertebrate community structure, their findings are just as relevant to appropriate monitoring of water quality parameters. This is particularly the case for estuaries, which are naturally highly variable in both space and time.

A range of physio-chemical parameters are commonly used to describe and monitor water quality within aquatic ecosystems. Nutrients (*i.e.* nitrite, nitrate, ammonia, phosphate, silicate), chlorophyll, turbidity, suspended solids, dissolved oxygen, salinity and temperature are often used to categorise or describe the 'health' of a waterway.

Deeley and Paling (1999) suggest that 'core' environmental indicators for estuaries are the minimum set of indicators (when monitored properly) that will provide information on major trends and impacts on estuarine ecosystems. They also suggest that there must be sufficient background knowledge (*i.e.* baseline data) of these indicators in order to describe departure from normal conditions. In addition, Pierson *et al*. (2002) stated that "good physical, chemical, water quality and ecological data for estuarine systems is absolutely foundational to robust predictions of appropriate environmental flows and review of implemented fresh water flow regimes".

Core National State of the Environment reporting environmental indicators for estuaries were determined to include nitrogen, chlorophyll *a* concentrations and turbidity as important indicators of ecosystem health. For routine monitoring it is important to incorporate chlorophyll *a* measurements with those of turbidity and the nutrient nitrogen (ANZECC 2000, Ward *et al.* 1998).

In marine systems, nitrogen is generally the limiting nutrient to plant growth. Increases in nitrogen can lead to eutrophication and excessive algal growth in estuaries, but initial changes to the ecosystem are more subtle. Dissolved inorganic forms of nitrogen (nitrite, nitrate, ammonia) are particularly important as they are known to be readily available for biological uptake. Levels of these nutrients should indicate the potential for eutrophication and algal blooms within the estuary (Ward *et al.* 1998). If data on nitrogen concentrations are not available, then the most appropriate surrogate is the concentration of chlorophyll *a* as an indicator of algal biomass (ANZECC 2000).

Turbidity is related to the 'murkiness' of water. It is quantified by the amount of suspended particles and colloidal material in the water, with minor contributions from coloured dissolved organic matter (*eg.* tannins). The turbidity of Tasmanian estuaries is an important issue in relation to benthic productivity, as many seagrass and algal bed communities depend on conditions of low turbidity (*i.e.* high light penetration) (Ward *et al.* 1998). Suspended solids are typically comprised of clay, silt, fine particulate organic and inorganic matter and microscopic organisms. Suspended solids correspond to non-filterable residues and tend to contribute most to the turbidity of the water.

Generally, a tendency for increases in nitrogen concentration, chlorophyll *a* concentration and/or turbidity within an estuary over time would be considered detrimental (Ward *et al.* 1998). Increases in the value of these core indicators would suggest a decrease in the health status of the estuary and the catchment.

Water quality parameters, such as salinity and temperature, are commonly monitored and can be descriptive of the general processes operating within the system. Dissolved oxygen is fundamental to organisms for respiration. In contrast to marine waters, the nutrient phosphorus is often the limiting nutrient in freshwater systems, although both P and Si have been found to be limiting in some situations (Deeley and Paling 1999).

1.5 Objectives

This study aimed to further develop the work of Edgar *et al.* (1999), by providing more detailed analysis of the physical and chemical nature of selected Tasmanian estuaries. The sampling regime was designed around ANZECC guidelines (ANZECC 2000) for water quality monitoring and assessment, to provide a robust baseline data set of water quality in Tasmanian estuaries. The methodology was intended to be readily repeatable to allow meaningful comparison with future assessments of estuarine water quality. The data were to be made readily available to all users and be in a format that would allow further analysis or modelling, such as for environmental flow requirements for estuaries. A significant outcome of the study was to provide draft trigger levels for water quality indicators in Tasmania.

The main objectives were to:

- describe spatial and temporal (intra-annual) patterns of variation in commonly measured water quality parameters, in 22 Tasmanian estuaries,
- provide baseline levels of water quality in each estuary,
- describe the relative state of health for each estuary,
- determine draft trigger levels for water quality indicators in Tasmania.

2. Methods

2.1 Sampling sites

Water quality parameters were studied at 22 Tasmanian estuaries (Fig. 1). The estuaries included in the study were chosen to reflect a range of physical estuarine groups (*eg.* barrier, river, inlet, lagoon) and estuaries of different conservation significance as determined by Edgar *et. al.* (1999). In addition, location within different bio-geographic regions (IMCRA Technical Group 1997), accessibility, availability of river flow data and likely relevance/interest to community groups or government agencies influenced the selection of estuaries. Large, previously studied estuaries such as the Derwent River (Coughanowr 1997), Tamar River (Pirzl and Coughanowr 1997), Huon River (Butler *et. al.* 2000), Bathurst Harbour (Edgar and Cresswell 1991) and Macquarie Harbour (Koehnken 1997, O'Connor *et. al*. 1996) were deliberately not included in the study. Due to accessibility, estuaries in the King and Furneaux Islands and the south-west of the State were not included in the study.

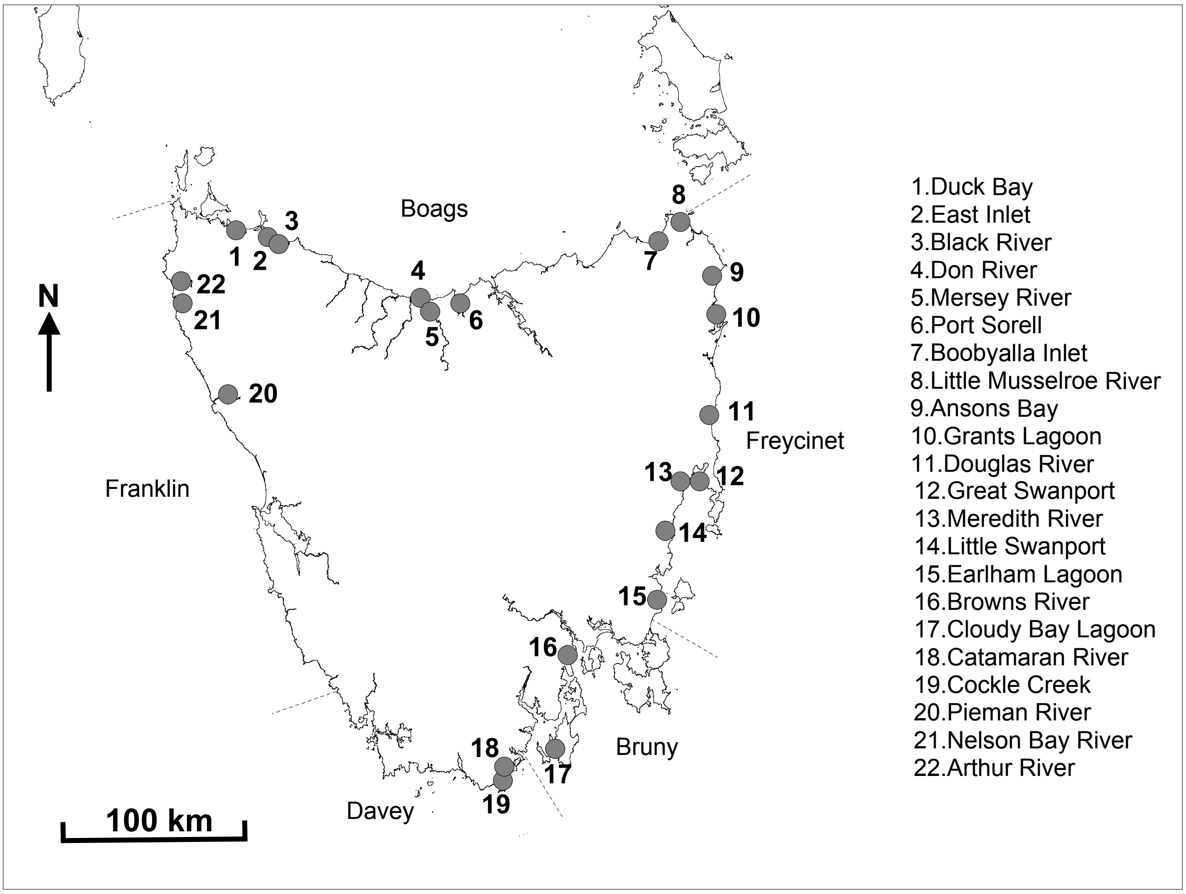

Fig. 1. Tasmania, by bio-region, showing the location of the 22 estuaries included in the water quality study.

Preliminary physio-chemical surveys of each estuary were conducted between April and June 1999. Based on these preliminary surveys, and geographic features that were interpreted as likely to influence flows, each estuary was then divided into three fixed zones. Zones were chosen to reflect the upper, middle and lower reaches (respectively, zones 1, 2 and 3) of each estuary.

At each estuary, two sampling sites were randomly selected within each zone (refer maps of each estuary in Results, section 3.2) and their position recorded (see Appendix 1) using a hand held Global Positioning System (GARMIN GPS 12). Sites could only be accessed in two of the three zones in each of the Don (Fig. 8) and Nelson Bay (Fig. 47) Rivers. All sites were fixed for the duration of the study.

2.2 Field sampling

Between July 1999 and June 2000, each estuary was sampled at two monthly intervals; a total of 6 sampling events at each estuary. Sampling was conducted from either a small boat or by wading and as close as possible to the time of low tide. Estuaries sampled by wading were either very shallow (generally less than 1 m depth at low tide) or the launching of a vessel was impractical (*i.e* Browns and Douglas Rivers).

The time of sampling (Australian Eastern Standard Time) at each site was recorded.

On each sampling occasion, salinity (ppt), temperature (°C) and dissolved oxygen (mg l^{-1}) were recorded at each site at the following depths (where applicable); the surface, 0.5, 1, 2, 4 and 10 m and at the bottom. During the study, salinity and temperature were measured with three instruments: a WTW LF196, WTW LF197 or Yeokal 602 Mk II. Dissolved oxygen (DO) was measured with either an OxyGuard Handy Mk III or WTW Oxy197 instrument. Due to equipment failure, DO was not always recorded

At each site, a two litre water sample was taken from just below the surface. Each water sample was stored in a plastic bottle, in the dark, for subsequent laboratory analysis of turbidity, nutrients (NO_x-N, PO_4-P, SiO_4-Si), chlorophyll *a* and suspended solids.

Some salinity, temperature, DO and turbidity data for February 2000 are unavailable, due to the theft of a vehicle containing field data sheets.

2.3 Laboratory analysis

Water samples were processed in the laboratory within 48 hours of collection, and were gently mixed before the removal of aliquots to be tested for each parameter.

Turbidity was determined using a portable turbidity meter (HACH 2100P Turbimeter).

For nutrient analysis, a 15 ml aliquot was filtered through a 1.2 µm pore size, 25 mm diameter glass fibre filter and frozen at -20°C.

For chlorophyll analysis, an aliquot of 0.20 - 0.80 L was vacuum filtered through a 1.2 µm pore size, 47 mm diameter glass fibre filter. Filters were stored in individual plastic petri dishes, wrapped in aluminium foil (to exclude light) and frozen at -20°C.

For analysis of suspended solids, a 0.15 - 0.80 L aliquot was vacuum filtered through a 1.2 µm pore size, 47 mm diameter glass fibre filter. Filters were stored in individual plastic petri dishes and frozen at -20°C. Prior to use, each filter had been heated to 500°C for at least 5 hours, cooled in a desiccator and pre-weighed.

Nutrients

Nutrient analysis was conducted up to 6 months after sample collection. Analyses were conducted using a Skalar® Segmented Flow Analyser and modified Skalar (1993) methods. Nutrient standards within the general range of the samples to be analysed (5, 10 and 20 µg l^{-1} for NO_x-N and PO_4-P; 100, 200 and 400 µg l^{-1} for SiO_4-Si) were prepared daily. For samples with relatively high nutrient concentrations, samples were diluted between 1:2 and 1:10 to be approximately within the range of standards used. Analytical runs consisted of approximately 18 samples per standard (*i.e.* each of the 3 standard concentrations then 18 samples, followed by each of the 3 standard concentrations then 18 samples, and so on). For NO_x-N analysis, the cadmium column was reconditioned if significant reduction efficiency was observed. Regression equations were calculated of peak heights for the standards and, thus, sample concentrations were determined by comparison of peak heights obtained for each sample against the peak heights of the standards.

Chlorohyll a

Chlorophyll *a* analysis was conducted up to 2 months after sample collection. Samples were processed in subdued light using modified methods of Strickland and Parsons (1968). Each filter was roughly chopped into a centrifuge tube containing 14 ml of 90% acetone and the contents sonicated (Lab-Line Instruments Labsonic System) for approximately one minute. Sonicated samples were held in the dark for 15 min and were then centrifuged for 10 minutes. The clear supernatant was decanted into another centrifuge tube, centrifuged for 5 minutes and then held on ice to minimise chlorophyll degradation. The supernatant was decanted into a 4 cm path length cuvette and the extinction value measured against a 90% acetone blank at 750, 663, 645 and 630 nm using a Pye Unicam SP8-100 UV spectrophotometer.

The concentration of chlorophyll *a* in the processed sample was calculated using the SCOR/UNESCO equation,

$$\text{C (chlorophyll } a\text{)} = 11.64E_{663} - 2.16E_{645} + 0.10E_{630} \quad \text{(Eqn. 1)}$$

where E stands for the extinction values, at wavelengths indicated by the subscripts (after correcting for the blank at 750 nm, the path length of cuvette and the volume of acetone) (Strickland and Parsons 1968).

The concentration of chlorophyll *a* in the water sample was calculated using the equation,

$$\text{Chlorophyll } a \text{ } (\mu\text{g l}^{-1}) = {}^{C}\!/_{V} \quad \text{(Eqn. 2)}$$

where C is the value obtained from Eqn. 1 and V is the volume of water sample filtered.

Suspended solids

Suspended solid analysis was conducted up to 3 months after sample collection. Filters were dried at 110°C for 2 hrs, before being cooled in a desiccator and weighed. This process was repeated until the difference between consecutive readings was less than 0.2 mg.

Filters were then heated at 480°C for 2 hrs, before being cooled in a desiccator and weighed. This process was repeated until the difference between consecutive readings was less than 0.2 mg.

The concentration (mg l^{-1}) of total suspended solids (*TSS*), volatile solids (*VSS*) and fixed solids (*FSS*) were calculated using the equations,

$$TSS = \frac{F_2 - F_1}{V} \qquad \text{(Eqn. 3)}$$

$$VSS = \frac{F_2 - F_3}{V} \qquad \text{(Eqn. 4)}$$

$$FSS = TSS - VSS \qquad \text{(Eqn. 5)}$$

where F_1 is the initial weight of the filter disc, F_2 is the weight after heating at 110°C, F_3 is the weight after heating at 480°C and V is the volume of water filtered.

2.4 Statistical analysis

All statistical analyses were conducted using SPSS 10.0 statistical software.

For each estuary, differences between time, zone and depth (surface and bottom) for each of salinity, temperature and dissolved oxygen were tested using analysis of variance (ANOVA). Values for each parameter were unlikely to be have been independent from values at previous or subsequent sampling occasions. Therefore, data were analysed by repeated measures ANOVA, using both a univariate and multivariate approach. Univariate ANOVA was conducted using Type III sums of squares and the probability value used was the Huynh-Feldt epsilon. Pillai's trace was the statistic used for the multivariate analysis. Homogeneity of variances was examined graphically and normality of the data was tested by examination of residuals. Generally, transformation of the data was unnecessary, as variances were independent of the means. However, in a small number of cases, data were transformed using the tranformation, ln (x + 0.1). Analysis was not conducted if a parameter had been measured on less than four occasions in an estuary. The results of repeated measures ANOVA for each estuary are shown in Appendix 3.

Average salinity, temperature and dissolved oxygen values recorded during the course of the study were presented graphically. Line graphs (as opposed to scatter plots with error bars) were used as they clearly demonstrate trends in vertical stratification and differences between zones.

For each estuary, Principal Components Analysis (PCA) of the water quality parameters from surface waters was used to explore patterns in the data. In the analysis, data were transformed [ln (x + 0.1)], missing values were excluded listwise and eigenvalues less than 1 were discarded. Parameters that had not been measured on more than one occasion in an estuary were excluded from the analysis. Results of PCA for each estuary are shown in Appendix 4.

3. Results

3.1 Estuary summary

3.1.1 Duck Bay

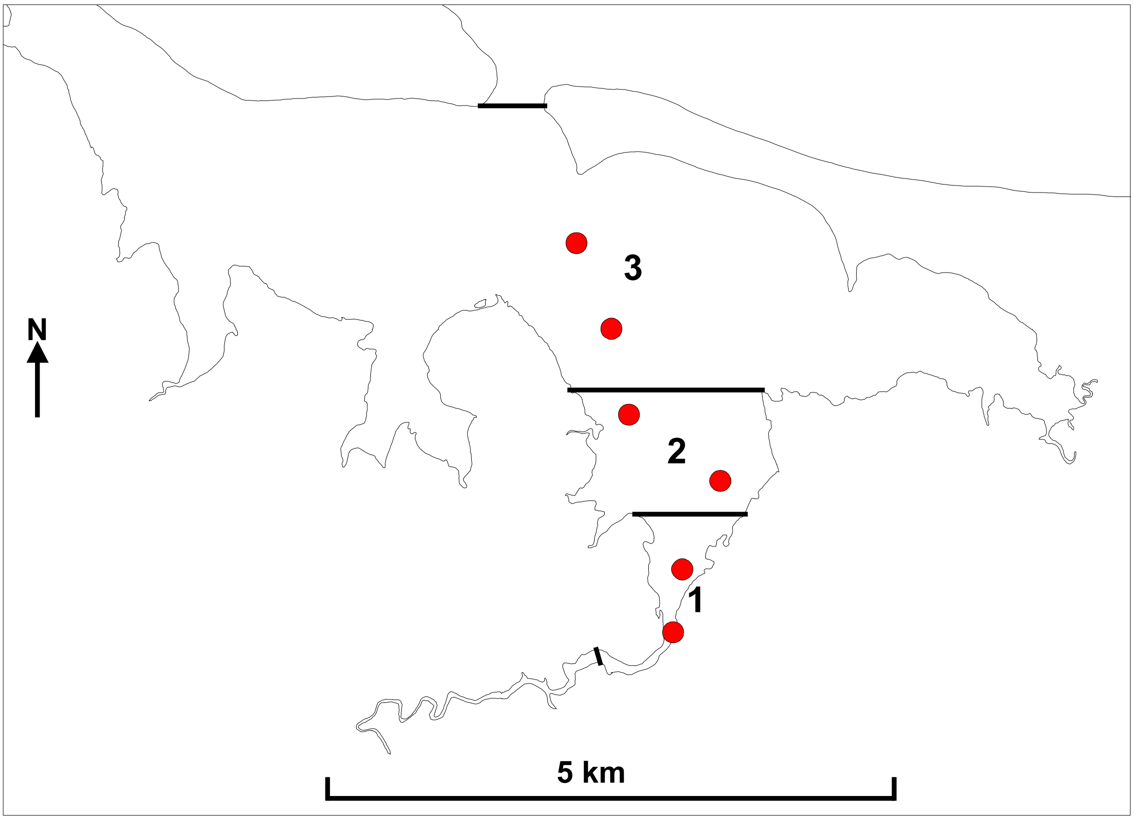

Fig. 2. Duck Bay showing fixed sampling sites and zones.

Duck Bay is an open estuary (Edgar *et al.* 1999) consisting of a relatively narrow channel and extensive exposed mudflats at low tide, particularly within zones 2 and 3. Average water depths within the channel are approximately 1 to 2 metres at low tide. Edgar *et al.* (1999) identified the Duck Bay estuary as being of low conservation significance. The National Land and Water Resources Audit identified Duck Bay as being a modified, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

There was a significant difference between salinity in surface and bottom waters and weak evidence that this behaviour was inconsistent over time (although T*D, $P = 0.273$ for the uni-variate test). In addition, the patterns of salinity over time were not consistent over all zones (Appendix 3). Generally, salinity increased towards the mouth of the estuary in all depths and zones. Within zone 1, salinity was highly variable over both time and depth with average values ranging from 1.8 to 14.0 ppt on the surface and 10.2 to 27.8 ppt on the bottom (Fig. 3). On some sampling occasions, surface salinity in this zone was up to 20 ppt lower than on the bottom. Within zone 2, average surface salinity ranged from 12.7 to 24.4 ppt, bottom salinity was between 13.4 and 32.2 ppt and surface salinity was up to 11 ppt lower than on the bottom on some sampling occasions. Salinity within zone 3 was not as variable by depth as the other zones. The greatest difference between the surface and bottom on any one sampling occasion was less than 6 ppt. Average salinity in zone 3 ranged from 22.2 to 32.5 ppt on the surface and 27.0 to 34.9 ppt on the bottom. Salinity values for depths other than the surface are not shown for February 2000 (missing data).

The patterns of temperature over time were not consistent by zone or depth, and there was weak evidence that the behaviour over time in the zones was inconsistent over depth (although T*Z*D Pillia's trace for the multi-variate test, P = 0.419) (Appendix 3). However, Fig. 3 shows that differences in temperature by depth within each zone were generally very small during any one sampling event, particularly in zones 2 and 3. On any one sampling occasion, temperature between any zone or depth was generally within 1 °C, the largest measured difference being 2 °C. Recorded temperatures ranged between 8.1 and 18.6 °C, although temperatures recorded in February 2000 (missing data) are likely to have been higher than this maximum.

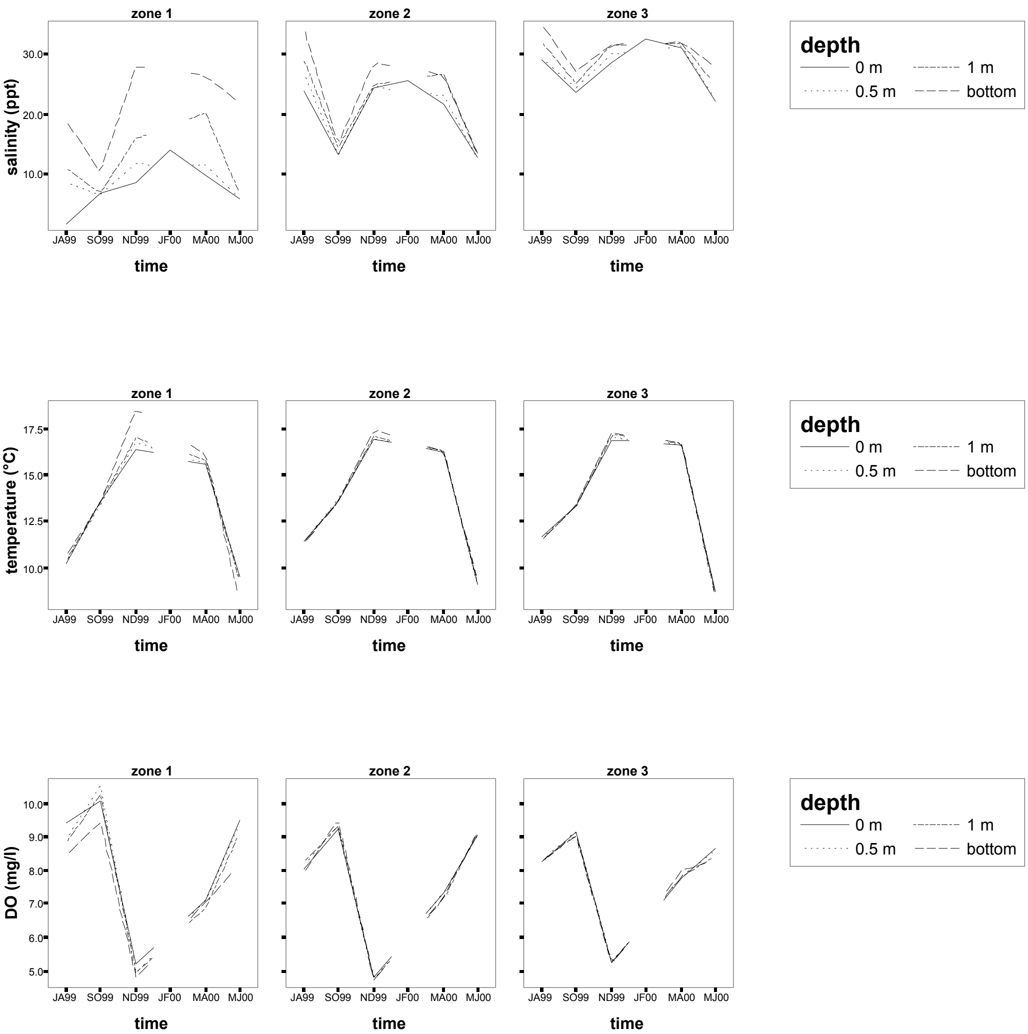

Fig. 3. Average salinity, temperature and dissolved oxygen, by zone and depth, Duck Bay (Jul/Aug 99 – May/Jun 00)

Table 2. Average values (n=6), yearly median and range (n=30 or 36) of water quality parameters in surface waters, Duck Bay (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	18.2 (14.0)	14.7 (8.0)	20.5 (9.8)	24.0 (8.6)	20.8 (10.0)	13.6 (7.9)	17.7	1.1	33.5
Temperature	°C	11.1 (0.8)	13.5 (0.2)	16.8 (0.3)		16.2 (0.5)	9.1 (0.4)	13.5	8.5	17.0
Dissolved O_2	mg l^{-1}	8.6 (0.7)	9.5 (0.5)	5.1 (0.4)		7.4 (0.3)	9.1 (0.4)	8.3	4.8	10.2
Turbidity	NTU	21.0 (18.4)	17.6 (8.6)	7.0 (4.1)	8.7 (3.9)	6.0 (1.8)	12.2 (6.5)	8.3	2.7	46.7
Chlorophyll *a*	µg l^{-1}	2.9 (2.1)	2.0 (0.5)	1.4 (0.3)	1.4 (0.6)	1.5 (0.5)	1.7 (0.6)	1.5	0.4	5.6
NO_x-N	µg l^{-1}	289 (252)	268 (139)	165 (121)	39 (28)	93 (72)	235 (106)	127	8	678
PO_4-P	µg l^{-1}	104 (62)	30 (11)	27 (8)	30 (3)	17 (3)	15 (5)	28	7	197
SiO_4-Si	µg l^{-1}	660 (420)	1850 (750)	1700 (1120)	1330 (1080)	2060 (1650)	1570 (730)	1175	130	4230
Total SS	mg l^{-1}	20.5 (7.8)	21.5 (7.8)	9.6 (3.8)	10.5 (4.0)	10.4 (1.8)	10.3 (3.9)	12.3	4.8	33.6
Volatile SS	mg l^{-1}	6.2 (3.6)	6.7 (2.8)	2.8 (1.1)	2.9 (1.0)	2.7 (0.7)	3.2 (1.1)	3.3	1.3	11.7
Fixed SS	mg l^{-1}	14.3 (4.3)	14.8 (5.0)	6.9 (2.7)	7.6 (3.0)	7.7 (1.2)	7.1 (2.8)	9.0	3.2	22.7

The behaviour of DO over time was not consistent over all zones and there was a significant interaction between zone and depth (Appendix 3). However, Fig. 3 shows that within each zone differences in DO by depth were generally small, particularly in zones 2 and 3. Within zone 1, the greatest recorded difference between depths was less than 1.5 mg l^{-1} on any one sampling occasion. Overall, DO ranged from 4.7 to 10.6 mg l^{-1}, with low values occurring during the warmer part of the year.

The first component of PCA of water quality parameters accounted for 60 % of the variation in the data and indicated that turbidity, suspended solids, chlorophyll and NO_x-N had a negative relationship with salinity. The second component, comprised solely by SiO_4-Si, explained 14% of the variation (Appendix 4).

Table 2 provides average values of water quality parameters, for each sampling occasion, in surface waters within Duck Bay. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

On most sampling occasions, levels of most of the main water quality indicators in Duck Bay were medium to very high, suggesting a relatively impacted estuarine system. Concentrations of most parameters reflected the horizontal salinity gradient, with significantly higher values recorded toward the head of the estuary, within zones 1 and 2. However, given the pattern of vertical stratification in the estuary, water samples taken from the surface are unlikely to be representative of conditions (*eg.* nutrients, etc) at all depths, particularly within zone 1.

Turbidity ranged from 2.7 to 46.7 NTU with a median value of 8.3 NTU (the second highest median turbidity recorded during the study) and on each sampling occasion, turbidity was much higher within zone 1 and 2 than at the mouth of the estuary. Chlorophyll *a* was relatively low throughout the estuary on most sampling occasions, the exception being August 1999 when a maximum value of 5.6 µg l^{-1} was recorded in zone 1. NO_x-N was high to very high on most sampling occasions, with a median value of 127 µg l^{-1} (the second highest median NO_x-N recorded during the study) and a maximum of 678 µg l^{-1}. Of all estuaries studied, only Boobyalla Inlet had a higher median NO_x-N concentration. High concentrations of PO_4-P were recorded throughout the estuary on most sampling occasions. The highest concentration of PO_4-P recorded in any estuary during the study (197 µg l^{-1}) was recorded in an August 1999 sample from zone 1. SiO_4-Si concentrations also tended to be high and ranged from 130 to 4230 µg l^{-1} with a median value of 1175 µg l^{-1}.

Water quality indicators suggest Duck Bay is a highly impacted and relatively unhealthy system, in comparison to most other estuaries in this study. NO_x-N and PO_4-P levels were high to very high suggesting significant input from anthropogenic sources. The surface water tended to be highly turbid, with increased nutrient levels (NO_x-N and PO_4-P), when the input of freshwater was highest. Low DO was recorded throughout the estuary in December 1999 and may have been even lower in February 2000 (missing data).

3.1.2 East Inlet

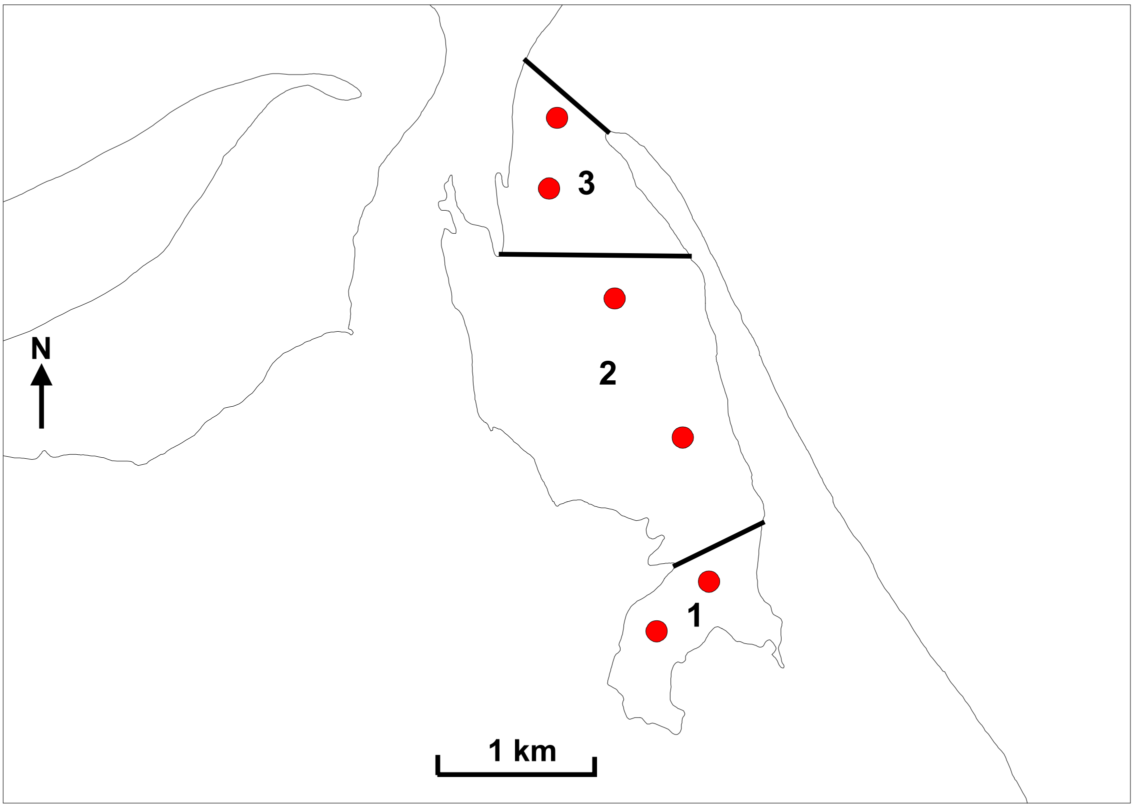

Fig. 4. East Inlet showing fixed sampling sites and zones.

East Inlet is a shallow marine inlet (Edgar *et al.* 1999) consisting of a relatively narrow channel and extensive sandflats at low tide. Average water depths at low tide are 1 to 2 m in zones 2 and 3 and generally less than 1 m in zone 1. Edgar *et al.* (1999) identified East Inlet as being of moderate conservation significance. The National Land and Water Resources Audit identified East Inlet as being a largely unmodified, wave dominated estuary (NLWRA 2002).

There was no significant difference between surface and bottom waters, for each of salinity, temperature and DO. However, for each parameter, the pattern over time was not consistent over all zones (although for DO, T*Z Pillia's trace for the multi-variate test, P = 0.183) (Appendix 3). Water samples taken from the surface are therefore likely to be representative of conditions (*eg*. nutrients, etc) at all depths.

Salinity ranged between 32.4 and 36.2 ppt, with a maximum difference of less than 2 ppt between zones during any sampling event. Fig. 5 shows that salinity tended to be higher towards the mouth for most of the year but was slightly higher (approaching hyper-saline) at the head of the estuary in December 1999.

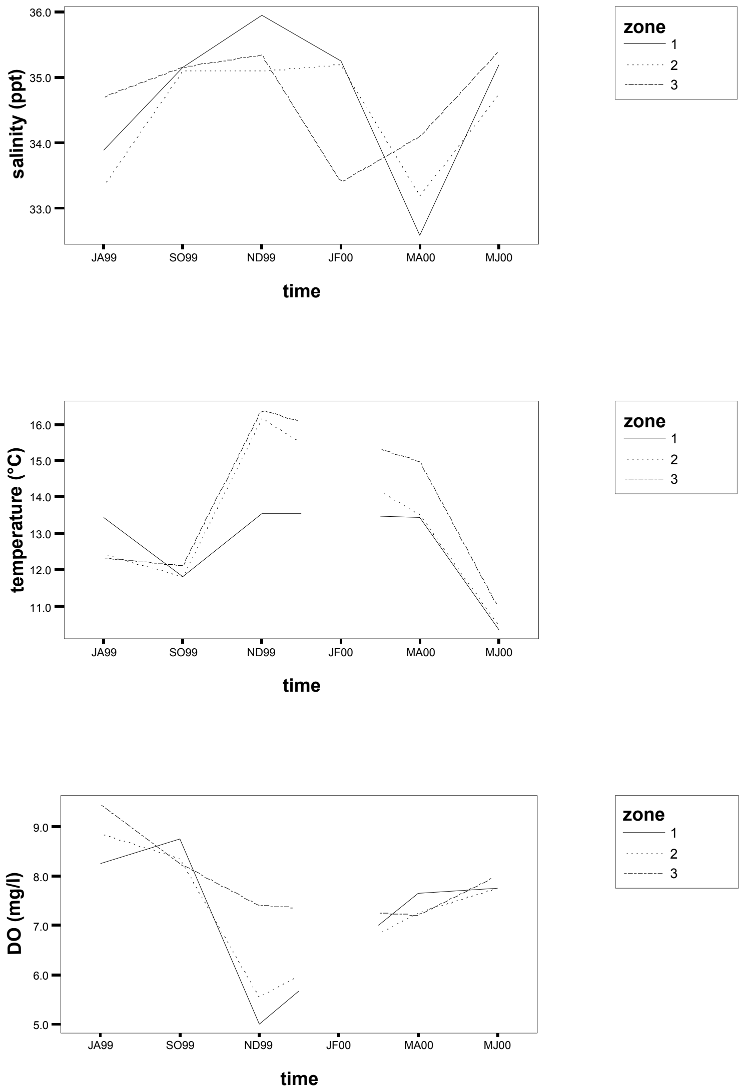

Fig. 5. Average surface salinity, temperature and dissolved oxygen, East Inlet (Jul/Aug 99 – May/Jun 00)

Table 3. Average values (n=6), yearly median and range (n=30 or 36) for water quality parameters of surface waters, East Inlet (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	34.0 (0.7)	35.1 (0.1)	35.5 (0.4)	34.6 (1.2)	33.3(0.7)	35.1 (0.3)	35.0	32.4	36.1
Temperature	°C	12.7 (0.6)	11.9 (0.4)	15.4 (1.4)		14.0(0.9)	10.6 (0.3)	12.5	10.2	16.4
Dissolved O_2	mg l^{-1}	8.9 (0.7)	8.5 (0.3)	6.0 (1.2)		7.4(0.3)	7.8 (0.2)	7.9	5.0	9.7
Turbidity	NTU	2.1 (0.5)	2.8 (0.8)	1.1 (0.2)	1.9 (0.2)	0.9(0.2)	1.7 (0.7)	1.7	0.6	3.9
Chlorophyll *a*	µg l^{-1}	0.1 (0.2)	0.0 (0.0)	4.4 (1.9)	0.6 (0.5)	0.0 (0.0)	0.2 (0.3)	0.0	0.0	6.3
NO_x-N	µg l^{-1}	5 (2)	3 (3)	1 (1)	1 (1)	2 (1)	3 (1)	2	0	8
PO_4-P	µg l^{-1}	20 (8)	12 (1)	8 (2)	10 (1)	11 (3)	11 (1)	11	6	34
SiO_4-Si	µg l^{-1}	80 (30)	80 (20)	80 (20)	80 (20)	90 (20)	80 (30)	80	40	120
Total SS	mg l^{-1}	8.7 (2.0)	11.4 (5.1)	4.7 (0.9)	3.6 (1.1)	6.1 (2.3)	4.3 (1.3)	5.3	2.4	21.1
Volatile SS	mg l^{-1}	2.4 (0.6)	2.5 (1.1)	1.4 (0.3)	1.0 (0.2)	1.1 (0.2)	1.0 (0.3)	1.4	0.8	4.8
Fixed SS	mg l^{-1}	6.3 (1.6)	8.8 (3.9)	3.3 (0.6)	2.5 (0.9)	5.0 (2.1)	3.3 (1.0)	3.9	1.5	16.3

Temperature ranged between 10.2 and 16.4 °C. However, maximum water temperatures experienced in East Inlet are likely to be significantly higher, as sampling was generally conducted early in the morning (Appendix 2) and data from late summer (February 2000) was missing. Average temperature between zones was generally within 1.5 °C during any sampling event, although the temperature at the head of the estuary was almost 3 °C less than the mouth during December 1999. In general, temperature tended to be higher at the mouth of the estuary (Fig. 5).

DO concentrations ranged between 5.0 and 9.8 mg /l. Average DO between zones was generally within 1 mg/l during any sampling event, although DO at the head of the estuary was almost 2.5 mg/l less than at the mouth during December 1999.

The first component of a PCA of water quality parameters accounted for only 43 % of the variation in the data and described a positive correlation between turbidity, suspended solids, PO_4-P and DO (Appendix 4).

Table 3 provides average values of water quality parameters, for each sampling occasion, in surface waters within East Inlet. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Generally, levels of all the main water quality indicators were low. Turbidity ranged from 0.6 to 3.9 NTU with a median value of 1.7 NTU, was relatively constant throughout the estuary, but tended to be slightly higher towards the head of the estuary. Chlorophyll *a* was not detected in most samples, as indicated by a median value of 0.0 µg l^{-1}, although there was a tendency for very low levels toward the head of the estuary. On one sampling occasion (December 1999) medium range concentrations were recorded in zones 1 and 2 with a maximum value of 6.3 µg l^{-1}. NO_x-N ranged from 0 to 8 µg l^{-1} with a median value of 2 µg l^{-1}. There was no consistent trend in NO_x-N concentrations between the zones. PO_4-P concentrations in the medium indicator range were recorded throughout the estuary on most sampling occasions, with high values recorded in August 1999. Overall, PO_4-P ranged from 6 to 34 µg l^{-1} with a median value of 11 µg l^{-1}.

Water quality indicators suggest that East Inlet is a relatively healthy estuary. However, PO_4-P levels tended to be medium to high suggesting some elevated input from anthropogenic sources. In addition, low dissolved oxygen concentrations, elevated chlorophyll levels and hyper-salinity were experienced at the head of the estuary in early summer.

3.1.3 Black River

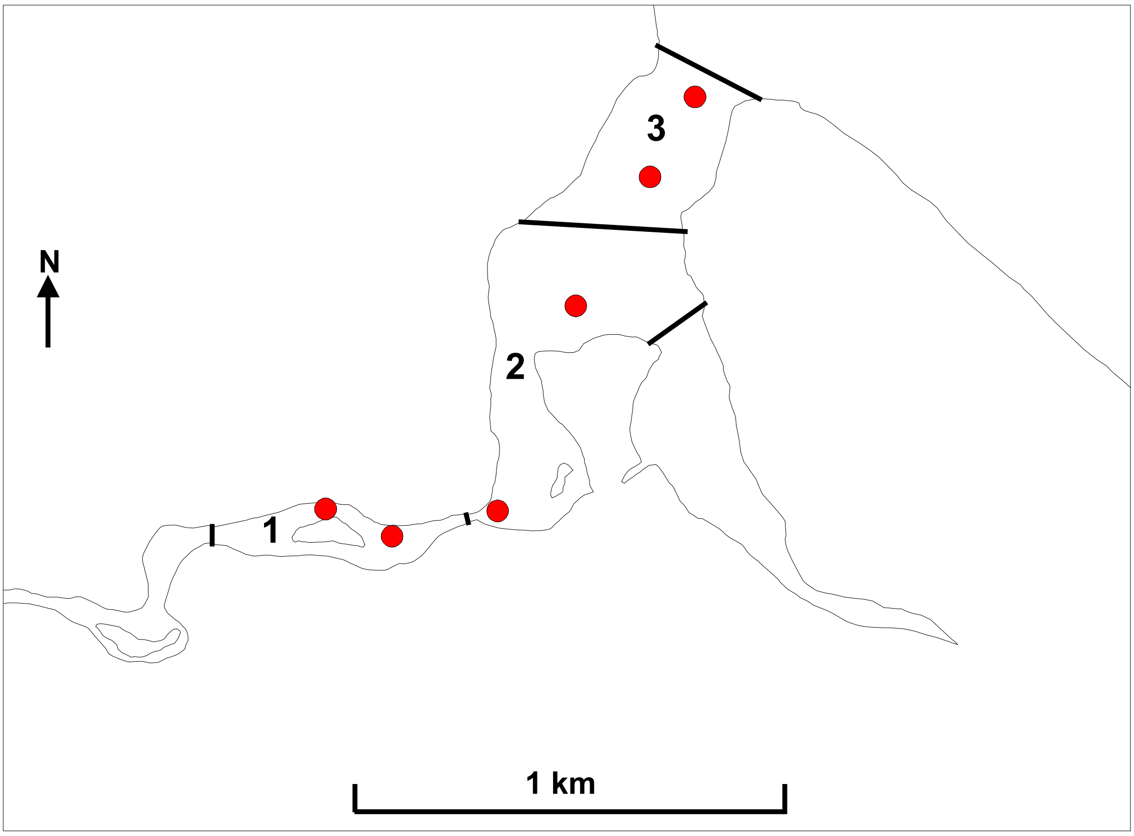

Fig. 6. Black River showing fixed sampling sites and zones.

Black River is a large mesotidal river estuary (Edgar *et al.* 1999). At low tide, the estuary consists of a relatively narrow channel with extensive sandflats within zone 3 and sandflats and mudflats within zone 2. There is a narrow, rocky constriction of the estuary at the boundary between zones 1 and 2, and a relatively deeper area (> 3 m) at this point. Apart from this deep region, average water depths within the rest of the estuary are generally around 1 m at low tide. Edgar *et al.* (1999) identified the Black River estuary as being of critical conservation significance. The significance of this estuary was attributed largely to it being the least impacted estuary of its type, with a relatively low proportion of agricultural land in the catchment and low population density. The National Land and Water Resources Audit identified the Black River estuary as being a near pristine, river dominated estuary (subclass: wave delta) (NLWRA 2002).

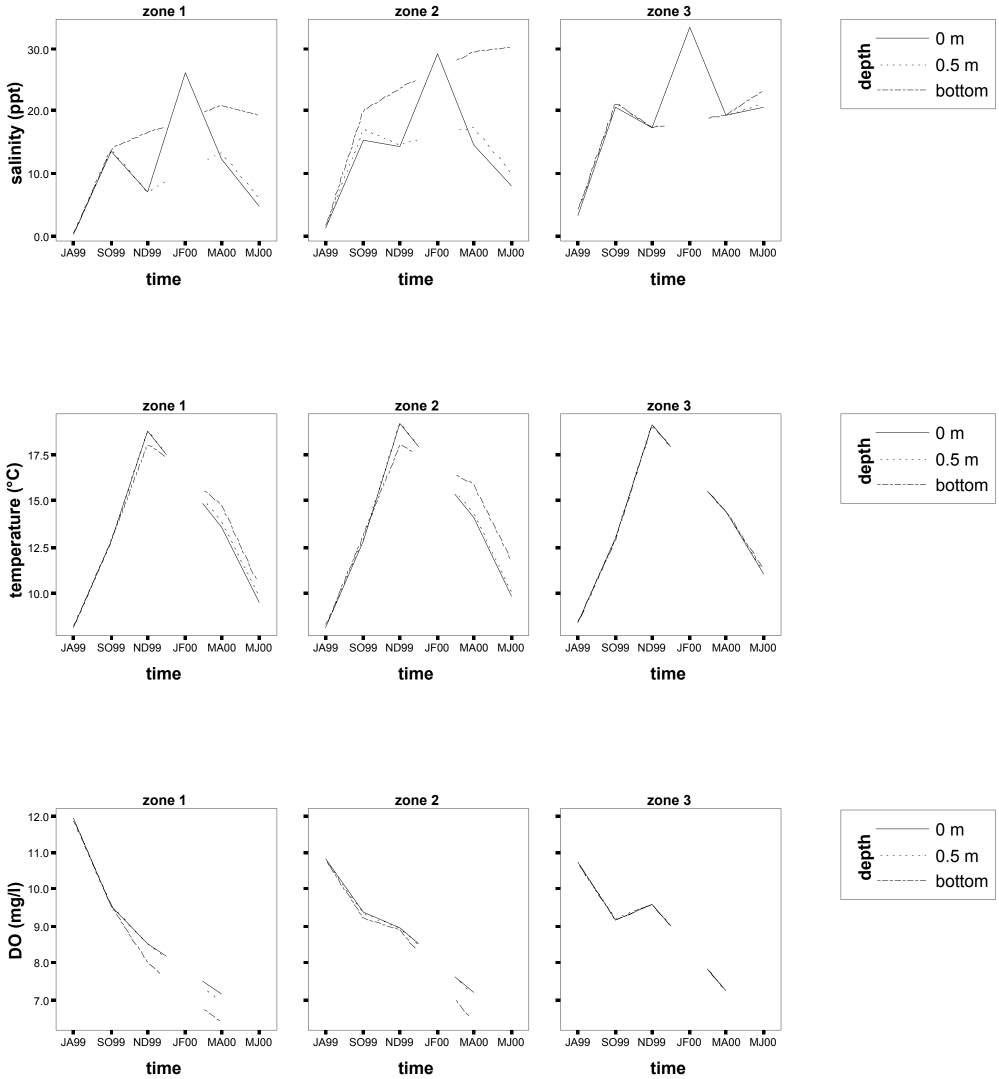

Fig. 7. Average salinity, temperature and DO, by zone and depth, Black River (Jul/Aug 99 – May/Jun 00)

The patterns of salinity over time were not consistent by depth and there was weak evidence that the behaviour of salinity over time within the zones was inconsistent over depth (although T*Z*D, P = 0.256 for the uni-variate test) (Appendix 3). Generally, salinity increased towards the mouth of the estuary in all depths and zones (Fig. 7). Zones 1 and 2 tended to be stratified, with similar salinity at the surface and 0.5m depth but with more saline water on the bottom. Stratification was not recorded in zone 1 on the first two sampling occasions and zone 3 showed very little stratification. Within zone 1, average salinity ranged between 0.1 and 26.1 ppt on the surface and 0.1 and 20.9 ppt on the bottom but salinity on the bottom in February 2000 (missing data) is likely to have been higher than this maximum. On some sampling occasions, surface salinity in zone 1 was up to 14 ppt lower than on the bottom. Within zone 2, average surface salinity ranged from 1.1 to 29.2 ppt and bottom salinity was between 1.5 and 30.2 ppt (again, bottom salinity is likely to have been higher than this maximum in February 2000). Surface salinity was up to 22 ppt less than on the bottom on some sampling occasions. Within the relatively deep section of the estuary, between zones 1 and 2, bottom waters were generally more saline than in any other part of the estuary. Average salinity in zone 3 ranged from 3.2 to 33.4 ppt, the greatest difference between the surface and bottom on any one sampling occasion being less than 2 ppt. Salinity values for depths other than the surface are not shown for February 2000 (missing data).

The patterns of temperature over time were not consistent by depth or zone (although T*Z, P = 0.278 for the uni-variate test) (Appendix 3). There was no thermal stratification in zone 3 but zones 1 and 2 showed slight differences by depth during some sampling events (Fig. 7). Temperatures recorded within the estuary ranged from 8.1 to 19.6 °C. The largest temperature difference between the surface and bottom on any one sampling occasion was less than 2 °C.

For DO, the patterns over time were not consistent by zone and there was a significant effect by depth (Fig. 7). There was no difference in DO by depth within zone 3. In zones 1 and 2, DO was up to 1 mg l^{-1} lower on the bottom than the surface on some sampling occasions. DO within the estuary ranged from 6.4 to 12.0 mg l^{-1} and differences between zones were generally small, being less than 1 mg l^{-1}. The range of DO values measured was greatest in zone 1 and lowest in zone 3.

The first component of a PCA of water quality parameters accounted for only 43 % of the variation in the data. This component described salinity, temperature and SiO_4-Si being negatively correlated with turbidity and NO_x-N. The second component, which described 29 % of the data, suggested a positive relationship between the suspended solids and PO_4-P (Appendix 4).

Table 4 provides average values of water quality parameters, for each sampling occasion, in surface waters within the Black River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Table 4. Average values (n=6), yearly median and range (n=24, 30 or 36) for water quality parameters of surface waters, Black River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	1.5 (1.5)	16.4 (3.4)	12.8 (5.0)	29.5 (3.3)	15.4(3.3)	11.1 (7.7)	12.7	0.1	21.8
Temperature	°C	8.2 (0.1)	12.9 (0.1)	19.1 (0.3)		14.0(0.4)	10.1 (0.7)	12.9	8.1	19.6
Dissolved O_2	mg l^{-1}	11.2 (0.6)	9.4 (0.2)	9.0 (0.5)		7.2(0.1)		9.3	7.1	12.3
Turbidity	NTU	8.9 (0.4)	3.9 (0.5)	3.8 (1.0)	3.0 (0.6)	2.9(0.3)	3.1 (0.4)	3.4	2.4	9.5
Chlorophyll *a*	µg l^{-1}	0.2 (0.2)	0.1 (0.1)	0.8 (0.3)	0.9 (0.5)	0.7 (0.2)	0.2 (0.0)	0.4	0.0	1.6
NO_x-N	µg l^{-1}	95 (21)	62 (18)	48 (14)	24 (12)	48 (17)	55 (16)	57	12	113
PO_4-P	µg l^{-1}	5 (4)	6 (2)	3 (1)	9 (4)	5 (2)	1 (1)	4	1	16
SiO_4-Si	µg l^{-1}	140 (100)	780 (80)	800 (110)	270 (100)	1290 (520)	1240 (100)	785	40	1870
Total SS	mg l^{-1}	9.1 (0.6)	64.0 (81.3)	8.3 (3.0)	15.9 (7.2)	18.5 (9.3)	5.2 (1.4)	10.5	3.3	205.6
Volatile SS	mg l^{-1}	3.7 (0.3)	4.9 (0.3)	3.1 (0.6)	6.3 (8.4)	2.6 (0.5)	2.4 (0.2)	3.1	1.9	23.5
Fixed SS	mg l^{-1}	5.4 (0.4)	59.1 (81.3)	5.3 (2.6)	9.6 (4.1)	15.9 (9.1)	2.8 (1.3)	6.8	1.1	200.6

Concentrations of most water quality indicators were low, although NO_x-N was medium to high on all sampling occasions. NO_x-N concentrations ranged from 12 to 113 µg l^{-1} with a median value of 57 µg l^{-1} and tended to be highest within zone 1. Turbidity ranged from 2.4 to 9.5 NTU with a median value of 3.4 NTU. On each sampling occasion, turbidity was relatively constant throughout the estuary but tended to be slightly higher towards the head of the estuary. Average concentrations of chlorophyll *a* were always less than 1 µg l^{-1}. PO_4-P ranged from 1to 16 µg l^{-1} with a median value of 4 µg l^{-1}. Concentrations tended to be highest towards the mouth of the estuary, suggesting mimimal imput of PO_4-P from the catchment.

Given the pattern of vertical stratification within zone 1 and 2, water samples taken from the surface are unlikely to be representative of conditions (*eg.* nutrients, etc) at all depths within these zones. Notwithstanding this, water quality indicators from surface waters suggest that the Black River estuary is a relatively healthy system, when compared to the other meso-tidal river estuaries included in this study. However, the medium to high NO_x-N values recorded require further investigation to determine if they relate to anthropogenic input or reflect naturally high concentrations on the north-west coast (ANZECC default trigger values are 190 µg l^{-1} for Tasmanian upland rivers).

3.1.4 Don River

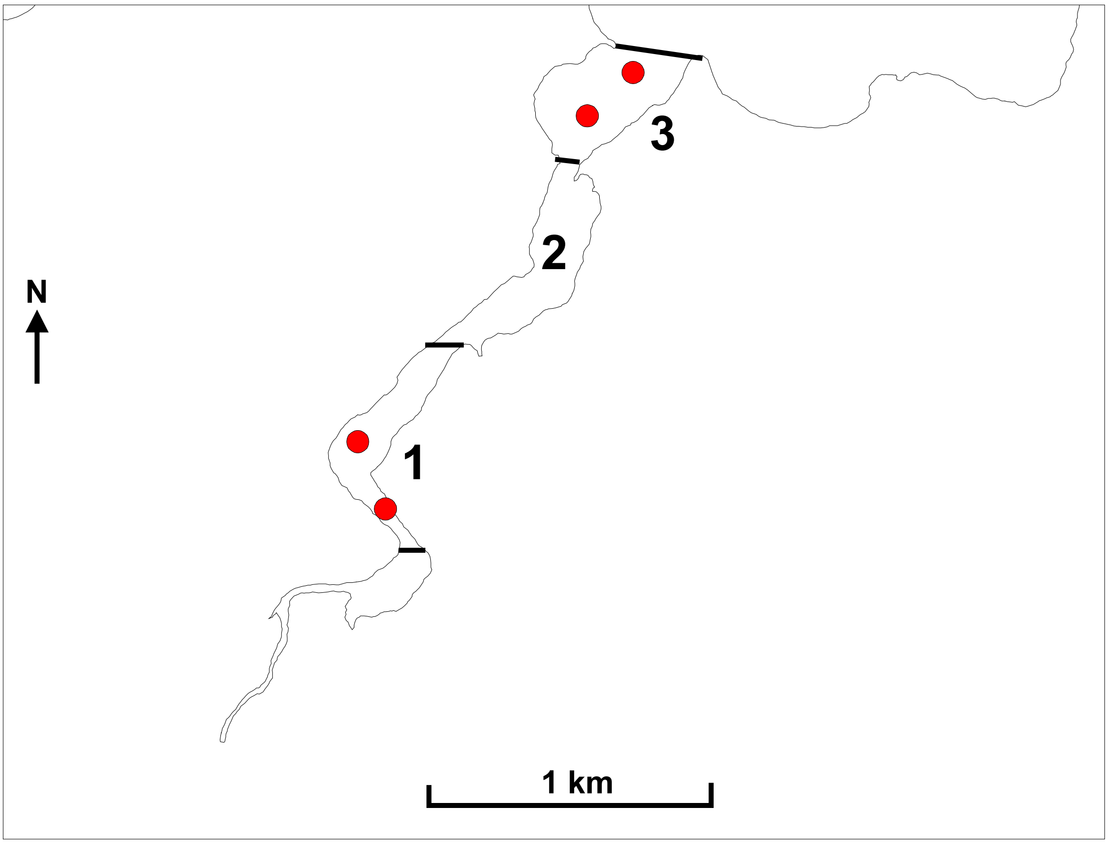

Fig. 8. Don River showing fixed sampling sites and zones.

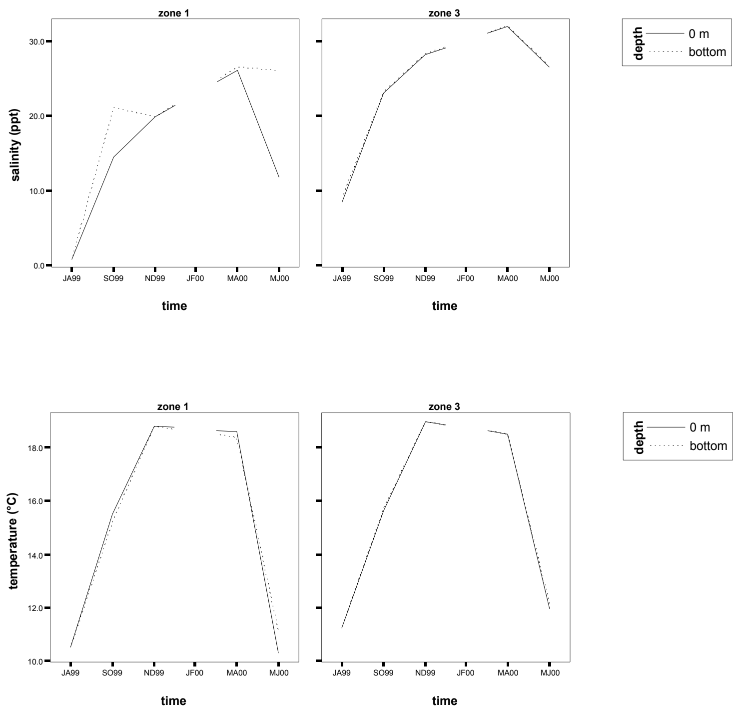

Fig. 9. Average salinity and temperature, by zone and depth, Don River (Jul/Aug 99 – May/Jun 00)

The Don River is a large mesotidal river estuary (Edgar *et al.* 1999). At low tide, the estuary consists of a relatively narrow channel with large mudflats within zone 1 and 2 and a rocky shore and mudflats within zone 3. At low tide, the average water depth within the estuary is less than 1 m. Zone 2 was not sampled due to difficulty in accessing the muddy tidal flats.

Edgar *et al.* (1999) identified the Don River estuary as being of low conservation significance. The National Land and Water Resources Audit identified the Don River estuary as being an extensively modified , wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

ANOVA results for the Don River estuary should be interpreted cautiously, as only two zones were sampled and analyses may be confounded due to small sample sizes.

The pattern of salinity over time by depth was not consistent within the zones (Appendix 3). Fig. 9 shows that that there was no vertical stratification within zone 3 with average salinity ranging from 8.5 to 32.0 ppt. In zone 1, stratification occurred on some sampling occasions. Average salinity within this zone ranged between 0.9 and 26.1 ppt on the surface and 0.8 and 26.6 ppt on the bottom. On some sampling occasions, surface salinity in this zone was up to 15 ppt lower than on the bottom.

The patterns of temperature over time were inconsistent for both depth and zone, however for each subject Pillia's trace for the multi-variate test was not significant (T*Z, P = 0.104; T*D, P = 252) (Appendix 3). Fig. 9 shows that there was very little difference in temperature between depth on any one sampling occasion and only a small difference between zones. On any one sampling occasion, temperatures between any zone or depth were generally within 0.5 °C, the largest difference measured being 2 °C. Temperatures recorded within the estuary ranged from 10.3 to 19.0 °C, although February 2000 (missing data) temperatures are likely to have been higher than this maximum.

DO was only sampled on three occasions with recorded values ranging from 6.7 to 11.0 mg/l.

The first component of a PCA of water quality parameters accounted for 48 % of the variation in the data. This component described a positive correlation between turbidity, the suspended solids and chlorophyll *a*. The second component, describing 37 % of the data, suggested a positive relationship between NO_x-N and SiO_4-Si concentrations, which were negatively correlated with salinity and temperature (Appendix 4).

Table 5 provides average values of water quality parameters, for each sampling occasion, in surface waters within the Don River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

On most sampling occasions, levels of the main water quality indicators in the Don River estuary were medium or very high, suggesting a relatively impacted estuarine system. Water samples taken from the surface within zone 3 were likely to be representative of conditions (*eg.* nutrients, etc) within this zone. However, on some sampling occasions within zone 1, surface waters would be atypical of conditions at all depths.

The median turbidity recorded within the Don River estuary was the highest of all the estuaries studied. Turbidity ranged from 3.4 to 355 NTU with a median value of 8.6 NTU, the highest median value recorded for the study. However, it should be noted that the extremely high values recorded in December 2000 occurred when sampling coincided with brief but heavy rain onto exposed mudflats resulting in silty runoff entering directly into the estuary.

Table 5. Average values (n=4), yearly median and range (n=12,20 or 24) for water quality parameters of surface waters, Don River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	4.7 (4.7)	18.8 (5.3)	24.0 (5.0)		29.0 (3.4)	19.2 (8.7)	22.0	0.7	32.2
Temperature	°C	10.9 (0.4)	15.6 (0.1)	18.9 (0.1)		18.6 (0.1)	11.1 (1.0)	15.6	10.1	19.0
Dissolved O_2	mg l^{-1}	10.2 (0.8)		8.3 (0.1)		7.1 (0.5)		8.4	6.7	11.0
Turbidity	NTU	50.0 (24.4)	9.8 (3.5)	125.3 (163.8)		8.1 (3.4)	4.5 (0.8)	8.6	3.4	355
Chlorophyll *a*	µg l^{-1}	2.5 (0.5)	0.7 (0.2)	25.6 (30.5)	17.6 (29.9)	0.7 (0.5)	0.1 (0.1)	0.8	0.0	62.1
NO_x-N	µg l^{-1}	1125 (275)	328 (60)	20 (18)	5 (5)	31 (15)	343 (172)	118	0	1326
PO_4-P	µg l^{-1}	8 (1)	4 (1)	31 (29)	11 (4)	13 (1)	8 (6)	9	2	70
SiO_4-Si	µg l^{-1}	3110 (570)	1530 (440)	860 (150)	530 (220)	580 (260)	2340 (1250)	1105	320	3590
Total SS	mg l^{-1}	40.2 (11.2)	8.9 (2.7)	24.9 (11.4)	12.4 (5.4)	24.0 (11.6)	5.3 (0.3)	15.6	4.8	54.3
Volatile SS	mg l^{-1}	7.8 (1.1)	2.5 (0.6)	5.5 (2.7)	3.9 (3.3)	3.2 (1.0)	1.8 (0.1)	3.2	1.4	9.2
Fixed SS	mg l^{-1}	32.4 (10.0)	6.4 (2.0)	19.4 (9.4)	8.5 (2.8)	20.8 (10.8)	3.5 (0.4)	11.7	2.9	45.2

Chlorophyll *a* showed large variability over time and between zones, ranging from 0.0 to 62.1 µg l^{-1}. Very high chlorophyll *a* was only recorded on two sampling occasions and only within zone 1. NO_x-N also showed a high degree of variability, particularly over time, with the highest concentrations recorded during the cooler period of the year when surface waters were less saline. NO_x-N ranged from 0 to 1326 µg l^{-1}, with a median value of 118 µg l^{-1}. The maximum value represented the single highest concentration of NO_x-N recorded in any estuary during the study. In comparison, concentrations of PO_4-P were generally medium to low on most sampling occasions, except during December 2000 when relatively high levels were recorded (associated with it raining during sampling). SiO_4-Si was highly variable, ranging from 320 to 3590 µg l^{-1} with a median value of 1105 µg l^{-1}.

Water quality parameters indicate that, in comparison to most other estuaries in this study, the Don River estuary is a highly impacted and relatively unhealthy system. NO_x-N levels associated with freshwater input from the catchment were very high and very high chlorophyll concentrations were recorded within zone 1 in December 1999 and February 2000. This suggests that at certain times of the year the Don River estuary is highly eutrophic.

3.1.5 Mersey River

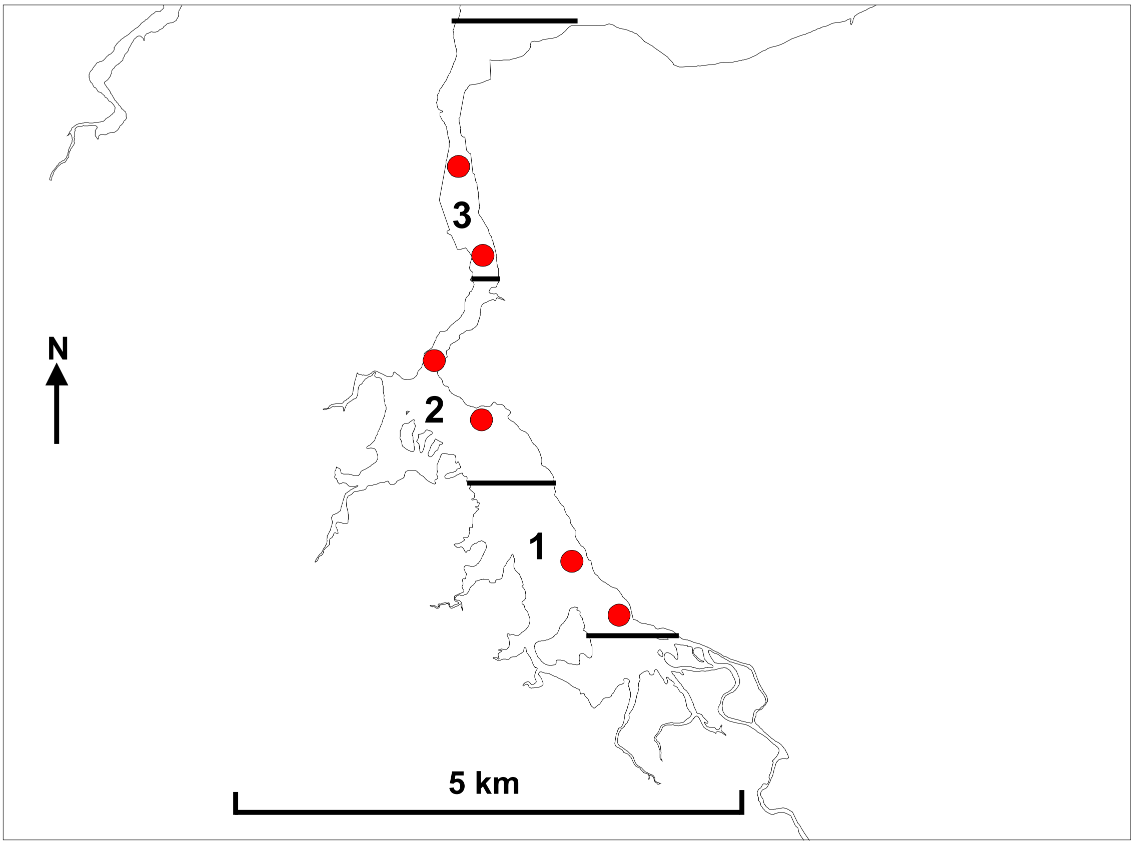

Fig. 10. Mersey River showing fixed sampling sites and zones.

The Mersey River is a large mesotidal river estuary (Edgar *et al.* 1999). At low tide, the estuary consists of extensive mudflats within zones 1 and 2. The shoreline within zone 3 is predominantly an artificial rock wall. The estuary is over 10 m deep within zone 3. Water depths at low tide range from approximately 2 to 5 m within zone 2 and 1 to 2 m within zone 1. Edgar *et al.* (1999) identified the Mersey River estuary as being of low conservation significance. The National Land and Water Resources Audit identified the Mersey River estuary as being an extensively modified , wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

Within the zones, the pattern of salinity over time was not consistent by depth (Appendix 3) although a trend for salinity to increase towards the mouth of the estuary in all depths and zones was evident. There was no obvious halocline with salinity tending to increase gradually with depth. In zone 1, salinity was highly variable over both time and depth with average values ranging from between 2.9 and 23.8 ppt on the surface and 7.4 and 32.4 ppt on the bottom (Fig. 11). On some sampling occasions, surface salinity in this zone was up to 17 ppt lower than on the bottom. Within zone 2, average surface salinity ranged from 7.5 to 30.0 ppt and bottom salinity was between 21.7 and 31.4 ppt. Surface salinity in zone 2 was up to 14 ppt greater than on the bottom on some sampling occasions. Salinity within zone 3 was not as variable by depth as the other zones. The greatest difference between the surface and bottom on any one sampling occasion was less than 4 ppt. Average salinity in zone 3 ranged from 24.6 to 32.6 ppt on the surface and 27.9 to 34.1 ppt on the bottom.

There was some weak evidence that the patterns of temperature over time in the zones was not consistent over depth (although T*Z*D Pillia's trace for the multi-variate test, $P = 0.667$) (Appendix 3). However, Fig. 11 shows that there was generally very little difference in temperature by depth within each zone. Temperatures ranged between 9.5 and 19.8 °C, although maximum water temperatures experienced in the Mersey River are likely to have been higher (February 2000 missing data). The temperature difference between depths within a zone was usually less than 1 °C. For any depth, temperature differences between zones were also generally within 1 °C although differences of up to 3 °C were recorded.

The patterns of DO over time were inconsistent for both depth and zone (Appendix 3). DO was less variable over time and depth in zone 3 than within the other zones (Fig. 11). Within zone 3, recorded DO concentrations ranged from 7.3 to 9.3 mg/l and average values were always within 0.5 mg/l between depths on any sampling occasion. In contrast, concentrations within zone 1 ranged from 6.8 to 10.5 mg/l and average values between depths were almost 2 mg/l different on some sampling occasions.

The first component of PCA of water quality parameters accounted for 52 % of the variation in the data and indicated that turbidity and suspended solids concentrations were negatively correlated with salinity levels. The second component described 32 % of the data and showed a negative relationship between temperature and NO_x-N (Appendix 4).

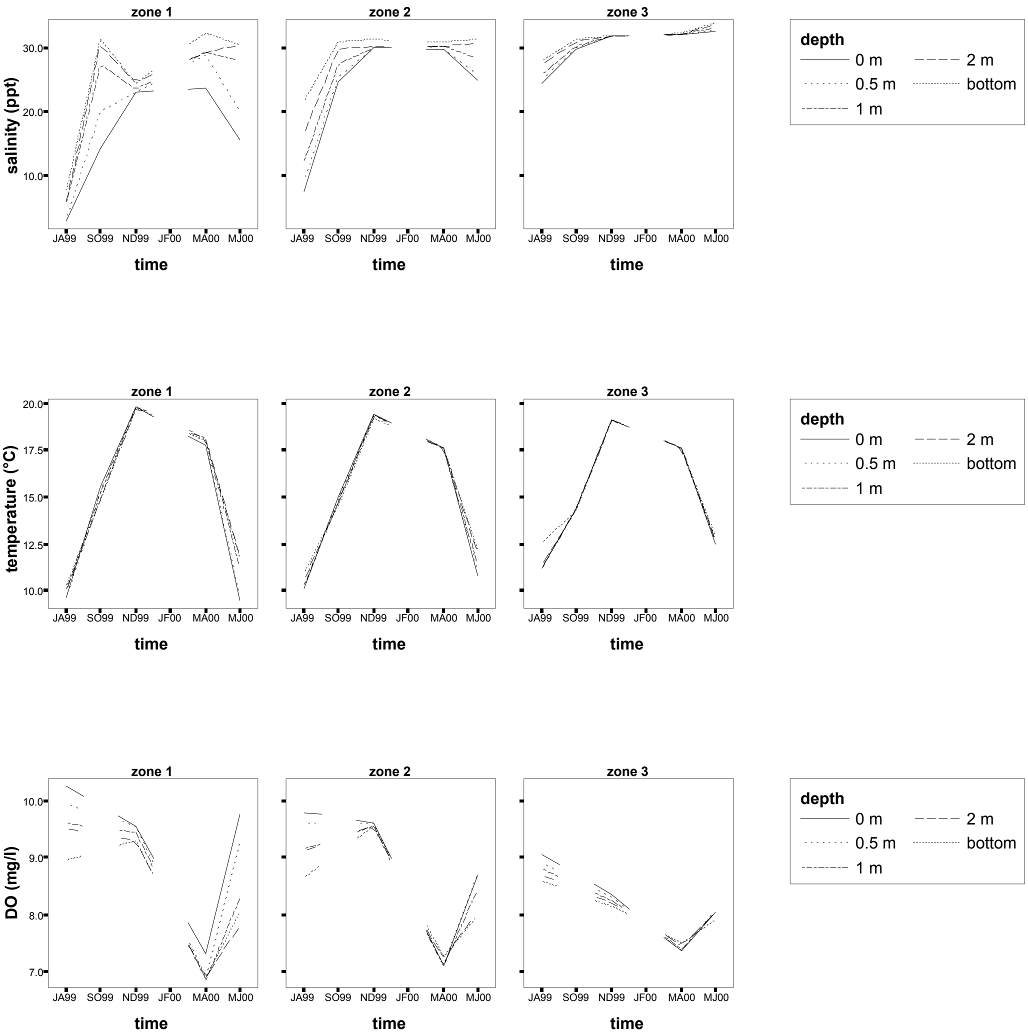

Fig. 11. Average salinity, temperature and DO, by zone and depth, Mersey River (Jul/Aug 99 – May/Jun 00)

Table 6 provides average values of water quality parameter, for each sampling occasion, in surface waters within the Mersey River. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

On all sampling occasions, levels of some of the main water quality indicators in the Mersey River estuary were medium to high, suggesting a moderately impacted estuarine system. Concentrations of most parameters were highest toward the head of the estuary. Given the pattern of vertical stratification within zone 1 and 2, water samples taken from the surface are unlikely to be representative of conditions (*eg.* nutrients, etc) at all depths but should approximate conditions within zone 3.

Table 6. Average values (n=6), yearly median and range (n=24,30 or 36) for water quality parameters of surface waters, Mersey River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	Units	JA 99	SO 99	ND 99	JF 00	MA 00	MJ 00	99 / 00	Min	Max
Salinity	ppt	11.6 (10.5)	22.9 (7.7)	28.3 (4.3)		28.6 (4.4)	24.3 (8.1)	26.8	1.4	33.2
Temperature	°C	10.3 (0.7)	15.0 (0.6)	19.4 (0.3)		17.7 (0.1)	10.9 (1.4)	15.0	8.8	19.9
Dissolved O_2	mg l^{-1}	9.7 (0.6)		9.2 (0.7)		7.3 (0.3)	8.8 (0.8)	8.8	6.8	10.5
Turbidity	NTU	12.0 (5.4)	3.6 (0.6)	13.3 (9.5)		6.3 (3.7)	3.1 (1.6)	5.5	1.7	26.0
Chlorophyll *a*	µg l^{-1}	0.8 (0.3)	0.3 (0.3)	3.1 (1.0)	0.9 (0.4)	0.7 (0.6)	0.2 (0.1)	0.5	0.1	4.7
NO_x-N	µg l^{-1}	289 (160)	65 (37)	19 (13)	24 (5)	22 (7)	61 (29)	31	8	507
PO_4-P	µg l^{-1}	8 (2)	8 (3)	9 (1)	15 (3)	13 (1)	10 (2)	11	4	20
SiO_4-Si	µg l^{-1}	1600 (850)	430 (220)	260 (90)	580 (130)	430 (170)	530 (300)	460	160	2480
Total SS	mg l^{-1}	14.0 (2.3)	7.5 (1.7)	13.0 (3.5)	11.0 (2.4)	10.5 (3.9)	5.2 (1.8)	9.5	3.3	17.3
Volatile SS	mg l^{-1}	3.3 (0.9)	1.9 (0.2)	2.7 (0.5)	1.9 (0.5)	2.1 (0.6)	1.2 (0.3)	1.9	0.9	4.6
Fixed SS	mg l^{-1}	10.7 (1.6)	5.7 (1.6)	10.4 (2.9)	9.1 (1.9)	8.5 (3.2)	4.0 (1.5)	7.6	2.3	14.2

Turbidity ranged from 1.7 to 26.0 NTU with a median value of 5.5 NTU and was generally much higher within zone 1 and 2 than at the mouth of the estuary. Chlorophyll *a* was relatively low throughout the estuary on most sampling occasions, with a median value of 0.5 µg l^{-1}. NO_x-N concentrations were medium to very high on all sampling occasions, with a median value of 31 µg l^{-1} and a maximum of 507 µg l^{-1}. PO_4-P concentrations were of a medium range, 4 to 20 µg l^{-1} , and were reasonably consistent throughout the study period. SiO_4-Si ranged from 160 to 2480 µg l^{-1} with a median value of 460 µg l^{-1}.

3.1.6 Port Sorell

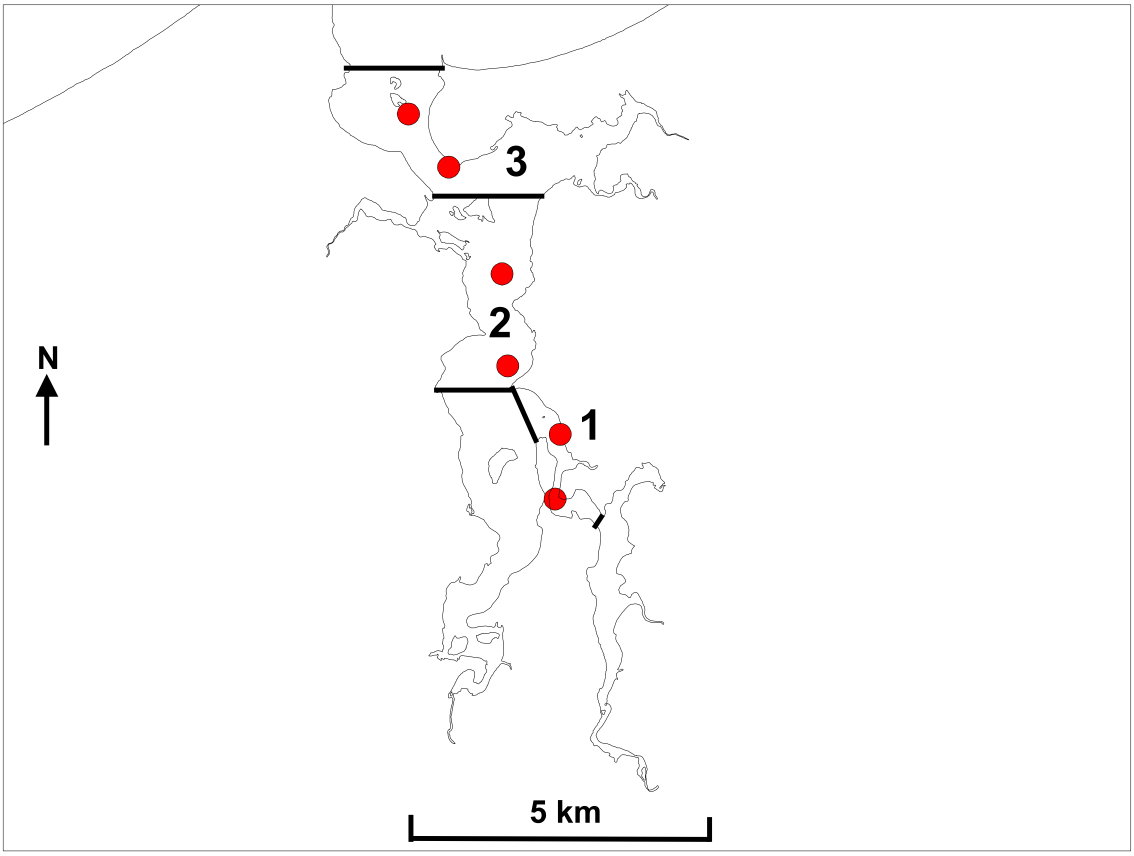

Fig. 12. Port Sorell showing fixed sampling sites and zones.

Port Sorell is an open estuary (Edgar *et al.* 1999), at low tide consisting of extensive sandflats within zones 2 and 3 and mudflats within zone 1. Average water depths at low tide are approximately 2 to 4 m in zones 2 and 3, and, 1 to 2 m in zone 1. Edgar *et al.* (1999) identified the Port Sorell estuary as being of low conservation significance. The National Land and Water Resources Audit identified Port Sorell as being a modified , wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

For each of salinity, temperature and DO, there was a significant effect by zone but not by depth. Therefore, at most times, water parameters measured at the surface are like to be representative of conditions at all depths. For each parameter, the patterns over time were not consistent over all zones although for temperature and DO this evidence was weak (T*Z Pillia's trace for the multi-variate test, P = 0.117 and P = 0.094, respectively) (Appendix 3).

Salinity values recorded within the estuary ranged between 3.6 and 35.5 ppt. While average values between zones were generally less than 3 ppt during any sampling event, large differences between the head and the mouth (20 ppt) were recorded following a large rainfall event in August 1999 (Fig. 13). Generally, salinity tended to increase from zone 1 to zone 3, although zone 1 approached hyper-salinity during February (missing data) and April 2000.

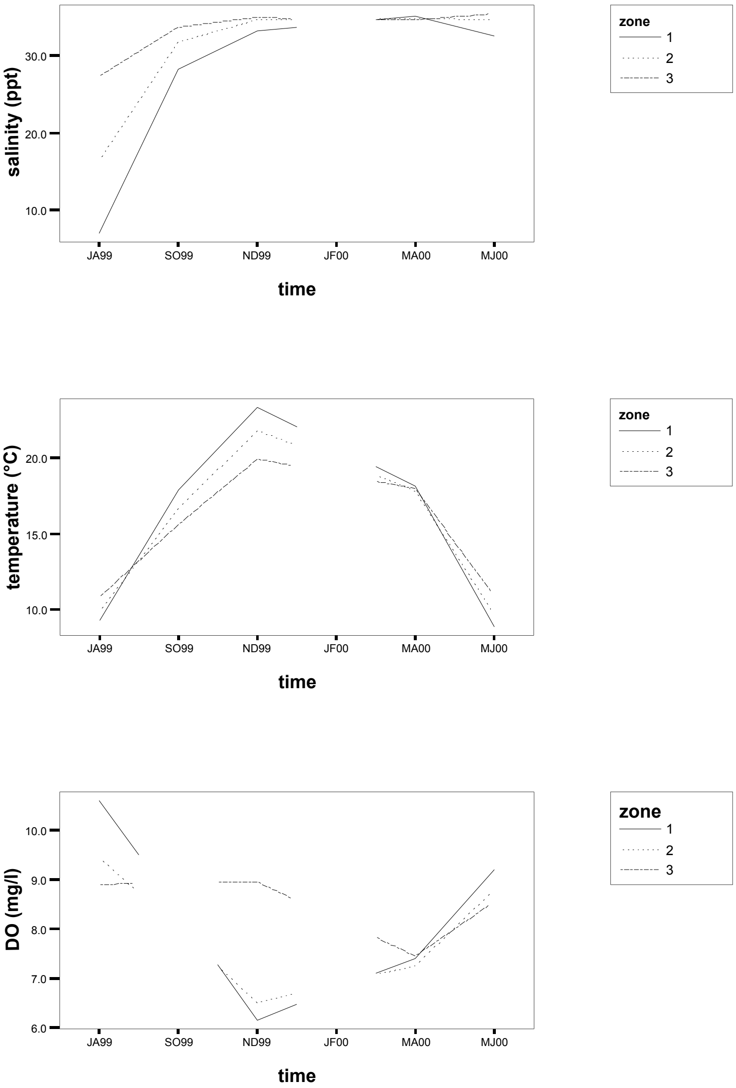

Fig. 13. Average surface salinity, temperature and DO, by zone, Port Sorell (Jul/Aug 99 – May/Jun 00)

The average temperature within the zones ranged from 8.9 to 23.4 °C (missing data from February 2000 is likely to have been higher) with differences between zones of up to 3.5 °C recorded on one sampling occasion. During the cooler period of the year, temperature tended to be highest at the mouth whereas during the warmer period of the year it was highest at the head of the estuary (Fig. 13).

DO concentrations ranged between 5.8 and 10.2 mg l^{-1} with the difference in average DO between zones being up to almost 3 mg l^{-1} during some sampling events (Fig. 13).

The first component of a PCA of water quality parameters accounted for 63 % of the variation in the data and described a correlation between turbidity, suspended solids and SiO_4-Si which were all negatively correlated with salinity. The second component, describing 20 % of the variation, described a relationship between temperature and chlorophyll *a,* which both had a negative relationship with NO_x-N (Appendix 4).

Table 7. Average values (n=6), yearly median and range (n=24, 30 or 36) for water quality parameters of surface waters, Port Sorell (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	16.9 (9.5)	31.3 (2.5)	34.2 (0.9)		34.8(0.3)	34.2 (1.4)	33.9	3.6	35.5
Temperature	°C	10.0 (0.8)	16.7 (1.1)	21.7 (1.6)		18.0(0.1)	9.8 (0.9)	16.7	8.9	23.9
Dissolved O_2	mg l^{-1}	9.7 (0.8)		7.2 (1.4)		7.4(0.1)	8.9 (0.3)	8.6	6.0	10.8
Turbidity	NTU	39.9 (31.3)	6.6 (2.7)	5.4 (1.6)		4.8(1.7)	3.1 (1.3)	5.4	1.7	96.3
Chlorophyll *a*	µg l^{-1}	1.3 (0.5)	1.2 (0.5)	1.6 (0.7)	0.9 (0.4)	0.5 (0.2)	0.3 (0.2)	0.8	0.1	2.5
NO_x-N	µg l^{-1}	217 (155)	5 (3)	0 (1)	2 (1)	4 (2)	11 (4)	4	0	460
PO_4-P	µg l^{-1}	12 (2)	22 (38)	9 (1)	8 (1)	9 (1)	6 (1)	8	4	100
SiO_4-Si	µg l^{-1}	790 (240)	310 (150)	220 (140)	110 (80)	170 (80)	200 (120)	215	30	1020
Total SS	mg l^{-1}	41.2 (30.1)	12.8 (4.1)	12.0 (3.4)	9.0 (1.4)	8.8 (1.8)	6.5 (2.4)	10.0	4.2	93.8
Volatile SS	mg l^{-1}	7.8 (5.1)	2.9 (4.6)	2.2 (0.5)	1.7 (0.2)	1.6 (0.2)	1.7 (0.4)	1.9	0	16.3
Fixed SS	mg l^{-1}	33.4 (25.0)	10.0 (4.1)	9.8 (2.9)	7.4 (1.1)	7.1 (1.6)	4.8 (2.1)	8.1	2.8	77.5

Table 7 provides average values of water quality parameters, for each sampling occasion, in surface waters within Port Sorell. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Levels of the main water quality indicators within Port Sorell were generally low to medium. However, very high turbidity and NO_x-N concentrations were recorded, following a flood event in August 1999, particularly towards the head of the estuary in zone 1 and 2. This suggests significant increases in some nutrients and suspended solids can occur towards the head of the estuary, associated with increased river flows, but that frequent tidal flushing of the estuary ensures a predominantly marine nature. Port Sorell is a moderately healthy estuary but significant reductions in water quality can occur in the upper estuary following rain.

Turbidity ranged from 1.7 to 96.3 NTU with a median value of 5.4 NTU and was generally much higher within zone 1 and 2 than at the mouth of the estuary. Chlorophyll *a* was relatively low throughout the estuary on most sampling occasions, with a median value of 0.8 µg l^{-1}. NO_x-N concentrations were low on all sampling occasions, the exception being August 1999 (after a flood) when an average value of 217 µg l^{-1} was recorded. NO_x-N ranged from 0 to 460 µg l^{-1} with a median value of 4 µg l^{-1}. PO_4-P concentrations were generally within a medium range of between 6 to 12 µg l^{-1}. However, a maximum value of 100 µg l^{-1} was recorded from a single sample in October 1999, suggesting that an error occurred while taking this sample. Interestingly, PO_4-P concentrations were not significantly elevated following the August 1999 flood event, indicating naturally low phosphate levels in this catchment. SiO_4-Si concentrations ranged from 30 to 1020 µg l^{-1}, with a median value of 215 µg l^{-1}.

3.1.7 Boobyalla Inlet (Ringarooma River)

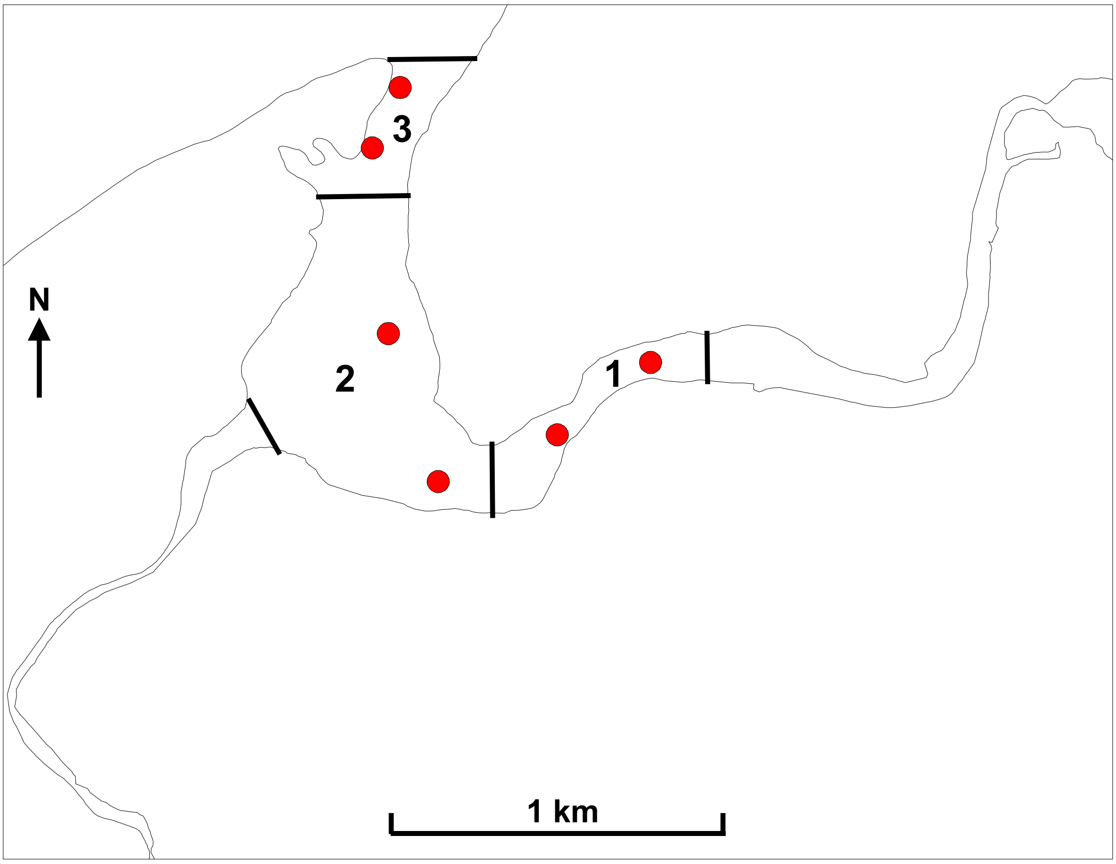

Fig. 14. Boobyalla Inlet showing fixed sampling sites and zones.

The Ringarooma River at Boobyalla Inlet is a large mesotidal river estuary (Edgar *et al.* 1999). At low tide, the estuary consists of a series of shallow winding channels and extensive sandflats within zones 2 and 3. In zone 1, the estuary narrows with small sandbanks being exposed at low tide. Average water depths within the estuary are less than 1 m at low tide. Edgar *et al.* (1999) identified Boobyalla Inlet as being of high conservation significance. The National Land and Water Resources Audit identified the Ringarooma River estuary as being an extensively modified, river dominated estuary (subclass: wave delta) (NLWRA 2002).

For each of salinity, temperature and DO, there was no significant depth effect (Appendix 3) therefore water parameters measured from surface waters should be representative of all depths. However, for each of these parameters the patterns over time were not consistent over the zones.

Salinity within Boobyalla Inlet was generally very low. Within zones 1 and 2 average salinity was less than 2 ppt on all sampling occasions except for March 2000 (Fig. 15) when average salinity was 7.9 and 12.1 ppt, respectively. Average salinity within zone 3 ranged from 0.3 to 18.3 ppt.

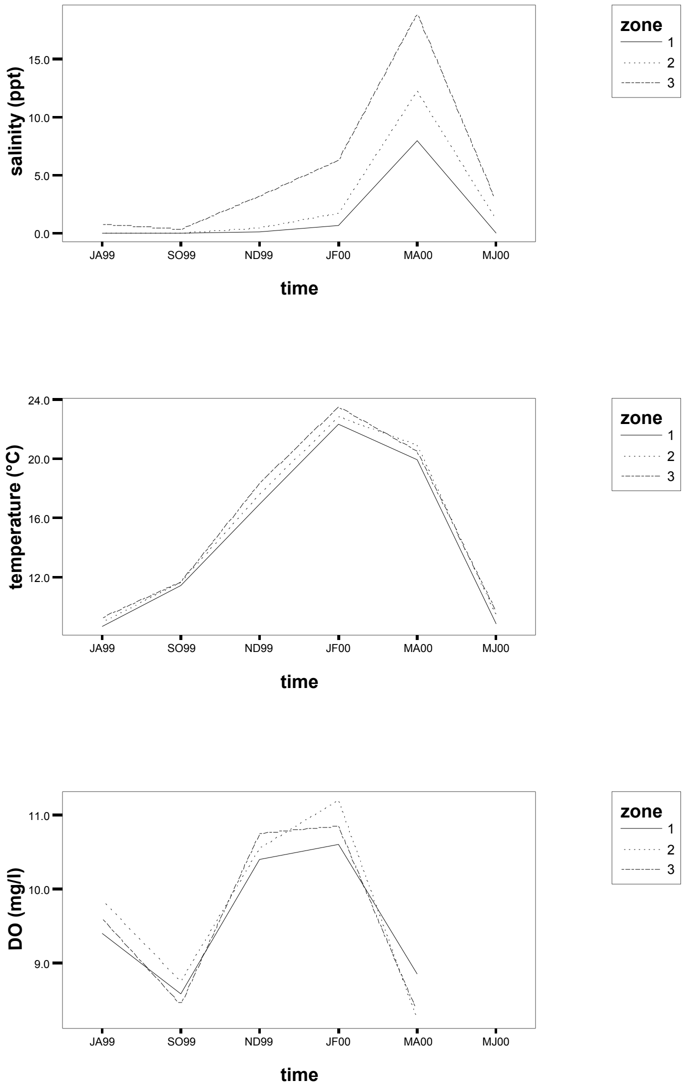

Fig. 15. Average surface salinity, temperature and DO, by zone, Boobyalla Inlet (Jul/Aug 99 – May/Jun 00)

Average temperature within the zones ranged from 8.7 to 23.5 °C (Fig. 15). Differences in temperature between zones on any one sampling occasion were generally less than 0.5 °C, although the mouth of the estuary was approximately 1.5 °C warmer than in zone 1 in both November 1999 and January 2000.

DO within the zones ranged from 8.3 to 11.2 mg/l with differences between zones on any one sampling occasion being less than 1 mg/l (Fig. 15).

The first component of a PCA of water quality parameters accounted for only 42 % of the variation in the data and suggested that, together, temperature and SiO_4-Si had a negatively correlation with turbidity. The second component (although no coefficient values ≥ 0.7) described an association between the suspended solids and salinity which were negatively related to NO_x-N concentrations (Appendix 4).

Table 8. Average values (n=6), yearly median and range (n=30 or 36) for water quality parameters of surface waters, Boobyalla Inlet (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	0.3 (0.4)	0.1 (0.1)	1.2 (1.5)	2.8 (2.8)	13.0 (6.0)	1.3 (1.4)	0.6	0.0	24.1
Temperature	°C	9.0 (0.3)	11.6 (0.2)	17.6 (0.7)	22.9 (0.5)	20.4 (0.6)	9.3 (0.5)	14.3	8.6	23.6
Dissolved O_2	mg l^{-1}	9.6 (0.2)	8.6 (0.1)	10.6 (0.2)	10.9 (0.4)	8.5 (0.4)		9.6	7.9	11.4
Turbidity	NTU	16.9 (1.3)	13.2 (2.7)	4.2 (0.3)	4.5 (0.7)	4.2 (1.2)	8.2 (0.7)	6.9	3.0	18.3
Chlorophyll *a*	µg l^{-1}	1.7 (0.7)	1.4 (0.3)	0.8 (0.1)	4.1 (3.6)	1.1 (1.2)	0.8 (0.4)	1.2	0.1	8.9
NO_x-N	µg l^{-1}	250 (76)	277 (51)	132 (8)	72 (13)	18 (4)	158 (28)	138	10	315
PO_4-P	µg l^{-1}	9 (8)	6 (7)	1 (1)	2 (1)	3 (1)	2 (1)	2	0	17
SiO_4-Si	µg l^{-1}	350 (70)	340 (160)	1580 (270)	2130 (200)	830 (290)	930 (700)	840	230	2400
Total SS	mg l^{-1}	11.4 (3.7)	115.5 (239.0)	4.5 (1.4)	13.5 (7.4)	13.1 (2.7)	10.4 (3.5)	10.9	3.3	603.1
Volatile SS	mg l^{-1}	2.8 (1.2)	5.0 (3.9)	1.6 (0.4)	5.9 (3.3)	2.8 (0.6)	2.5 (0.7)	3.0	0.6	12.2
Fixed SS	mg l^{-1}	8.6 (2.6)	110.5 (235.9)	2.9 (1.0)	7.6 (4.2)	10.3 (2.3)	7.9 (2.8)	8.2	2.0	591.7

Table 8 provides average values of water quality parameters, for each sampling occasion, in surface waters within Boobyalla Inlet. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Turbidity was medium to high on all sampling occasions, recorded values ranging between 3.0 and 18.3 NTU. However, values are likely to be strongly influenced by tannin with the Ringarooma River. Chlorophyll *a* was generally low throughout the estuary on most sampling occasions, except for January 2000 when a maximum concentration of 8.9 µg l^{-1} was recorded within zone 1. The median NO_x-N concentration of 138 µg l^{-1} was the highest recorded for any estuary during the study. NO_x-N was high to very high in all samples, except during March 2000 when the salinity was highest. PO_4-P concentrations were low to medium, ranging between 0 and 17 µg l^{-1}. SiO_4-Si concentrations ranged from 230 to 2400 µg l^{-1}, with a median value of 840 µg l^{-1}.

The extremely high levels of nitrogen indicate that significant inputs enter the estuary from the Ringarooma catchment. This, coupled with elevated chlorophyll levels recorded towards the head of the estuary, suggest that Boobyalla Inlet may be highly susceptible to eutrophication, particularly within the upper reaches, above zone 1of this study. However, the medium to high NO_x-N values recorded require further investigation to determine if they relate to anthropogenic input or reflect naturally high concentrations in this catchment (ANZECC default trigger values are 190 µg l^{-1} for Tasmanian upland rivers).

3.1.8 Little Musselroe River

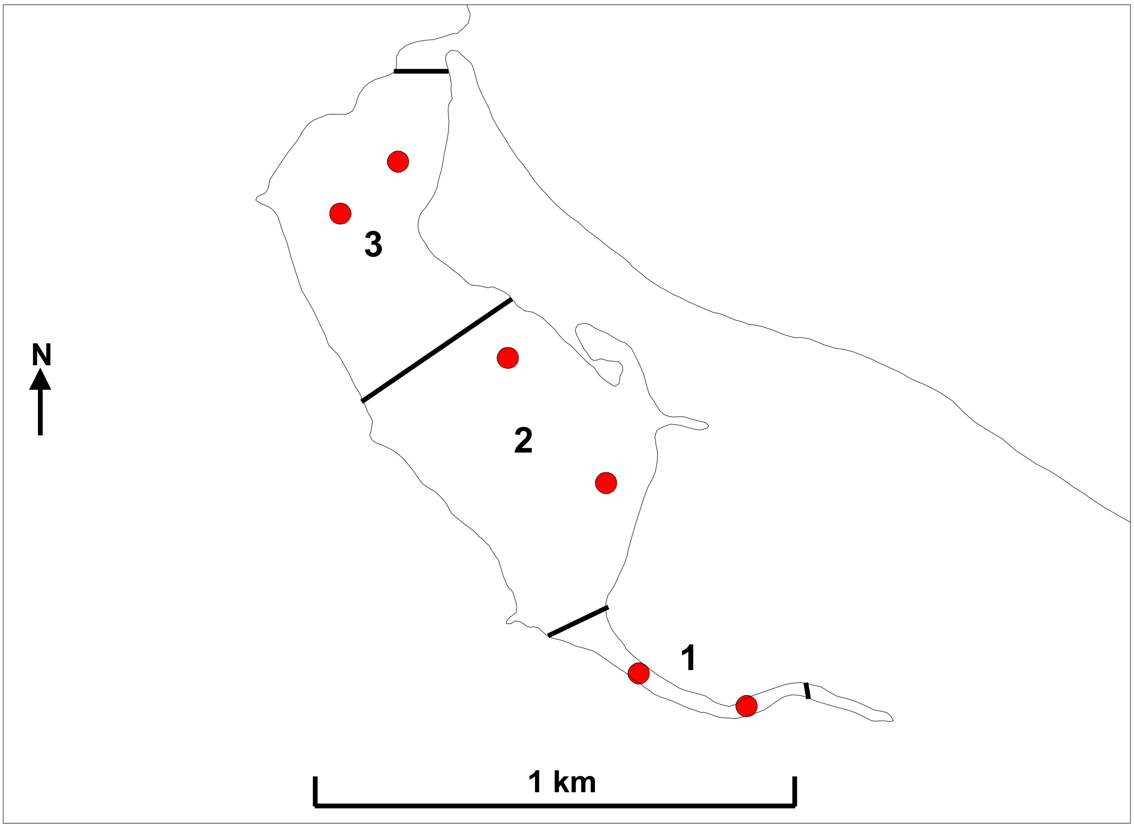

Fig. 16. Little Musselroe River showing fixed sampling sites and zones

The estuary of the Little Musselroe River has been classified as a marine inlet (Edgar *et al.* 1999). At low tide, zone 2 and 3 consists of extensive sandflats and a shallow, narrow channel that is generally less than 0.5 m deep. In zone 1, the estuary narrows considerably and is deeper, with maximum water depths of approximately 1.5 m at low tide. Edgar *et al.* (1999) identified the Little Musselroe River estuary as being of moderate conservation significance. The National Land and Water Resources Audit identified the Little Musselroe River estuary as being a modified, river dominated estuary (subclass: wave delta) (NLWRA 2002).

The patterns of salinity over time were not consistent by zone or depth (Appendix 3). However, differences of greater than 1 ppt between the surface and bottom were only observed in zone 1 (Fig. 17). Average salinity ranged from 22.3 to 34.8 ppt in zone 3 and 13.0 to 34.3 ppt in zone 2. In zone 1, surface salinity ranged from 5.9 to 32.8 ppt and bottom salinity from 29.5 to 35.2 ppt. Zone 1 was stratified on all sampling occasions, except March 2000, with the maximum difference recorded between the surface and bottom being almost 21 ppt. In comparison to other estuaries classified as marine inlets (Edgar *et al.* 1999), the Little Musselroe River estuary has a relatively low salinity and tends to have water chemistry similar to some of the open estuaries.

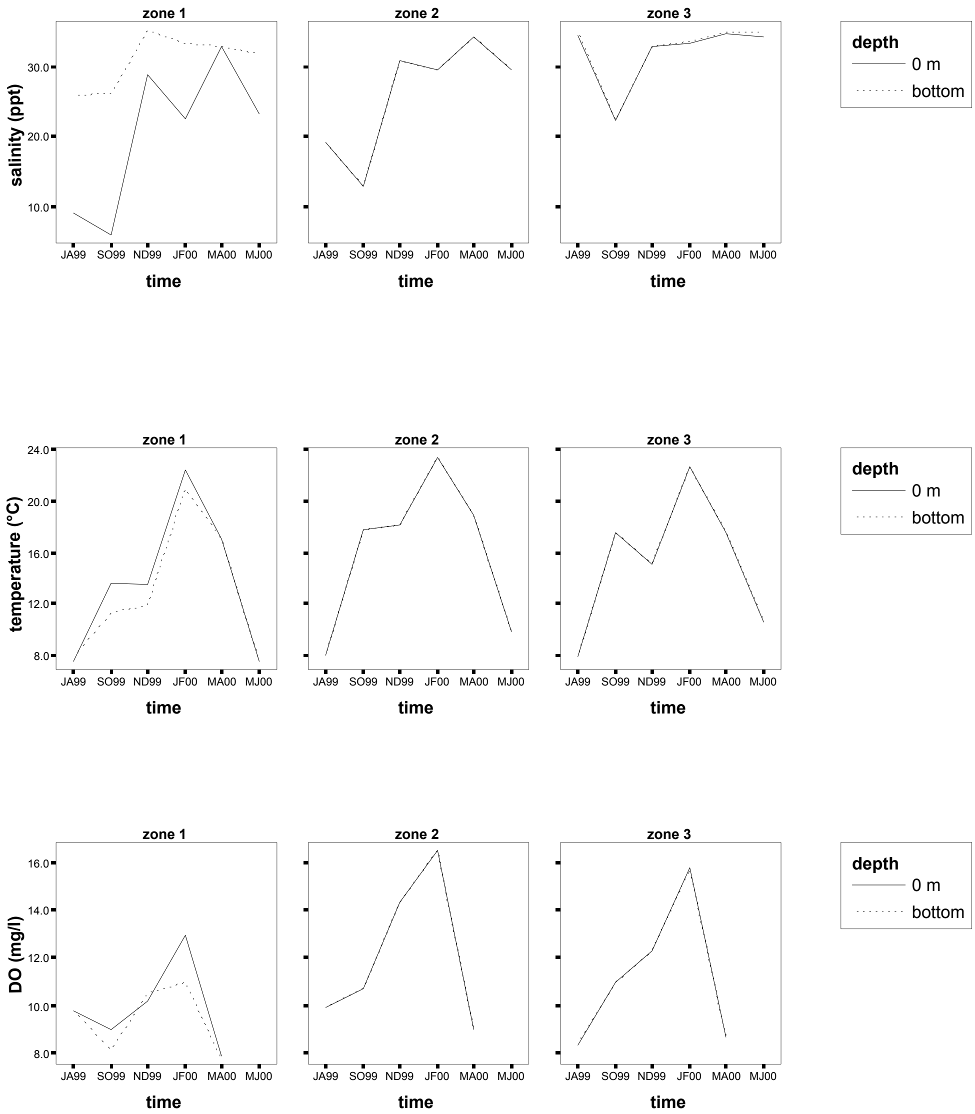

Fig. 17. Average salinity, temperature and DO, by zone and depth, Little Musselroe River (Jul/Aug 99 – May/Jun 00)

The patterns of temperature over time were not consistent by zone or depth (although T*D, P = 0.690 for the uni-variate test) (Appendix 3) although temperature differences between the surface and bottom waters were only observed within zone 1 (Fig. 17). Average temperature ranged from 7.9 to 22.7 °C in zone 3 and 8.1 to 23.5 °C in zone 2 . In zone 1, surface temperature ranged from 7.5 to 22.5 °C and bottom temperature from 7.9 to 21.0 °C.

The patterns of DO over time were not consistent by zone or depth (although T*Z, Pillia's trace P = 0.070 for the multi-variate test and T*D, P = 0.934 for the uni-variate test) (Appendix 3). As was observed for salinity and temperature, differences between the surface and bottom were only observed in zone 1 (Fig. 17). Average DO ranged from 8.3 to 15.8 mg/l in zone 3 and 9.9 to 16.6 mg/l in zone 2 . In zone 1, surface DO ranged from 7.9 to 13.0 mg/l and bottom DO from 7.7 to 11.0 mg/l. The difference between surface and bottom DO was generally less than 1 mg/l on any one sampling occasion, but was 2 mg/l during January 2000.

The first component of a PCA of water quality parameters accounted for only 39 % of the variation in the data and described a correlation between turbidity and suspended solids. The second component, which accounted for 27 % of variation, showed a negative relationship between salinity and NO_x-N concentrations (Appendix 4).

Table 9 provides average values of water quality parameters, for each sampling occasion, in surface waters within the Little Musselroe River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

In most of the estuary, water quality parameters measured from surface waters are likely to be representative of all depths, except within the upper reaches that are subjected to reduced tidal flushing. Levels of most of the main water quality indicators were low to medium although high PO_4-P and very high chlorophyll *a* concentrations were recorded within zone 1 and 2 in January 2000. Chlorophyll *a* was highly variable between sampling occasions ranging from 0.0 to 74.5 μg l^{-1}. Turbidity was low to medium and ranged from 1.1 to 17.3 NTU, with a median value of 3.4 NTU, and on each sampling occasion, was much higher within zone 1 and 2 than at the mouth of the estuary. NO_x-N was generally very low with a median value of 4 μg l^{-1}. SiO_4-Si concentrations ranged from 20 to 840 μg l^{-1}.

The very high chlorophyll levels recorded in zone 1 in January 2000 suggest that the upper estuary may be highly susceptible to eutrophication. In contrast to Boobyalla Inlet where this risk may be associated with increased nitrogen levels, in Little Musselroe this may be linked to increased phosphate entering the estuary.

Table 9. Average values (n=6), yearly median and range (n=30 or 36) for water quality parameters of surface waters, Little Musselroe River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	Units	JA 99	SO 99	ND 99	JF 00	MA 00	MJ 00	99 / 00	Min	Max
Salinity	ppt	20.8 (11.6)	13.7 (7.5)	30.9 (2.1)	28.5 (5.1)	34.0 (1.1)	29.0 (4.9)	30.2	4.6	35.2
Temperature	°C	7.8 (0.3)	16.3 (2.4)	15.6 (2.1)	22.9 (0.8)	17.8 (0.9)	9.3 (1.5)	15.9	7.4	24.3
Dissolved O_2	mg l^{-1}	9.3 (0.9)	10.2 (1.1)	12.3 (2.4)	15.1 (2.3)	8.5 (0.7)		10.611	7.8	18.6
Turbidity	NTU	4.0 (1.7)	5.4 (1.8)	1.6 (0.4)	6.7 (5.7)	3.5 (1.9)	3.9 (1.8)	3.4	1.1	17.3
Chlorophyll *a*	μg l^{-1}	1.6 (1.7)	0.6 (0.6)	0.0 (0.0)	33.2 (32.3)	2.5 (1.3)	2.0 (1.3)	1.1	0.0	74.5
NO_x-N	μg l^{-1}	16 (18)	24 (17)	1 (1)	2 (1)	1 (1)	13 (11)	4	0	51
PO_4-P	μg l^{-1}	8 (3)	7 (2)	4 (1)	17 (8)	4 (1)	6 (1)	6	2	28
SiO_4-Si	μg l^{-1}	350 (300)	430 (120)	40 (10)	260 (300)	50 (30)	270 (170)	90	20	840
Total SS	mg l^{-1}	6.9 (3.6)	8.8 (1.9)	4.8 (1.8)	7.6 (2.7)	17.5 (18.6)	12.5 (7.0)	7.5	2.3	54.6
Volatile SS	mg l^{-1}	2.5 (1.7)	2.7 (0.4)	1.6 (0.5)	3.4 (1.3)	3.5 (1.7)	4.1 (1.9)	2.5	0.9	6.5
Fixed SS	mg l^{-1}	4.4 (2.0)	6.1 (1.7)	3.2 (1.3)	4.2 (1.5)	14.0 (17.0)	8.4 (5.2)	4.9	1.4	48.1

3.1.9 Anson Bay

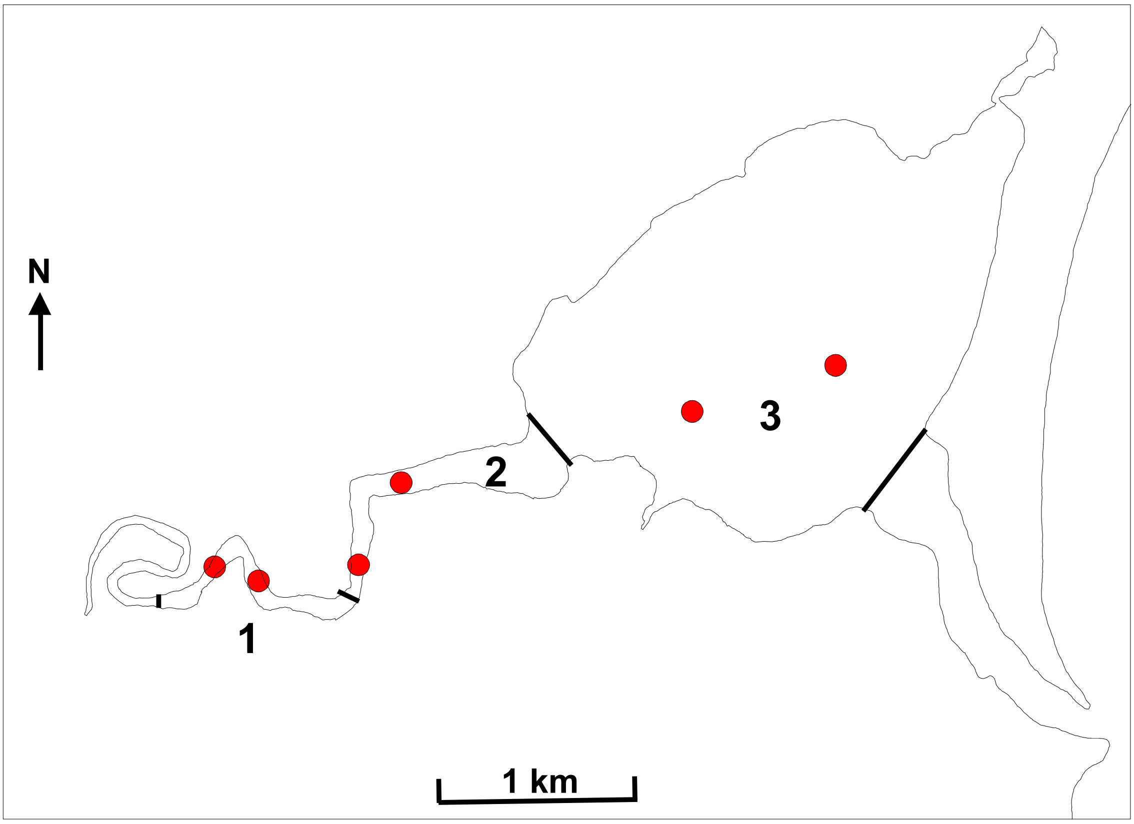

Fig. 18. Ansons Bay showing fixed sampling sites and zones.

Ansons Bay is an open estuary (Edgar *et al.* 1999) consisting of a large exposed bay in zone 3, narrowing considerably to a winding river estuary in zones 2 and 1. Average water depths within the estuary are 2 to 4 m. Edgar *et al.* (1999) identified Ansons Bay as being of moderate conservation significance. The National Land and Water Resources Audit identified Ansons Bay as being a modified, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

The patterns of salinity, temperature and DO over time within the zones were not consistent by depth (although for DO, T*Z*D Pillia's trace for the multi-variate test P = 0.337) (Appendix 3). Generally, the estuary was highly stratified, particularly within zone 1 and 2 and water quality parameters measured at the surface are unlikely to be representative of conditions experienced greater than 0.5 m below the surface (Fig. 19).

Salinity was highly variable over both time and depth, particularly within zone 1 and 2 which showed similar trends by depth. These zones were generally highly stratified with a distinct halocline approximately 0.5 m below the surface. The salinity below 1 m was more uniform. Within zones 1 and 2, average values ranged from between 0.1 ppt and 25.9 ppt on the surface and 7.4 and 35.0 ppt on the bottom (Fig. 19). In zone 3, average values ranged from between 11.5 ppt and 34.9 ppt on the surface and 26.2 and 34.9 ppt on the bottom. For all zones, bottom salinity was greater than 30 ppt on all sampling occasions except for the January 2000 sample which followed an extreme rainfall event.

Fig. 19 shows that temperature difference between surface and bottom waters of up to 4.5 °C were recorded within Ansons Bay. Some thermal stratification was evident within zone 1 and 2 on most sampling occasions. In contrast, temperature within zone 3 was generally uniform by depth except for January 2000 when a difference of 2.5 °C (associated with the distinct halocline) was recorded following an extreme flood event. Overall, average temperature within the zones ranged from 10.0 to 21.1 °C.

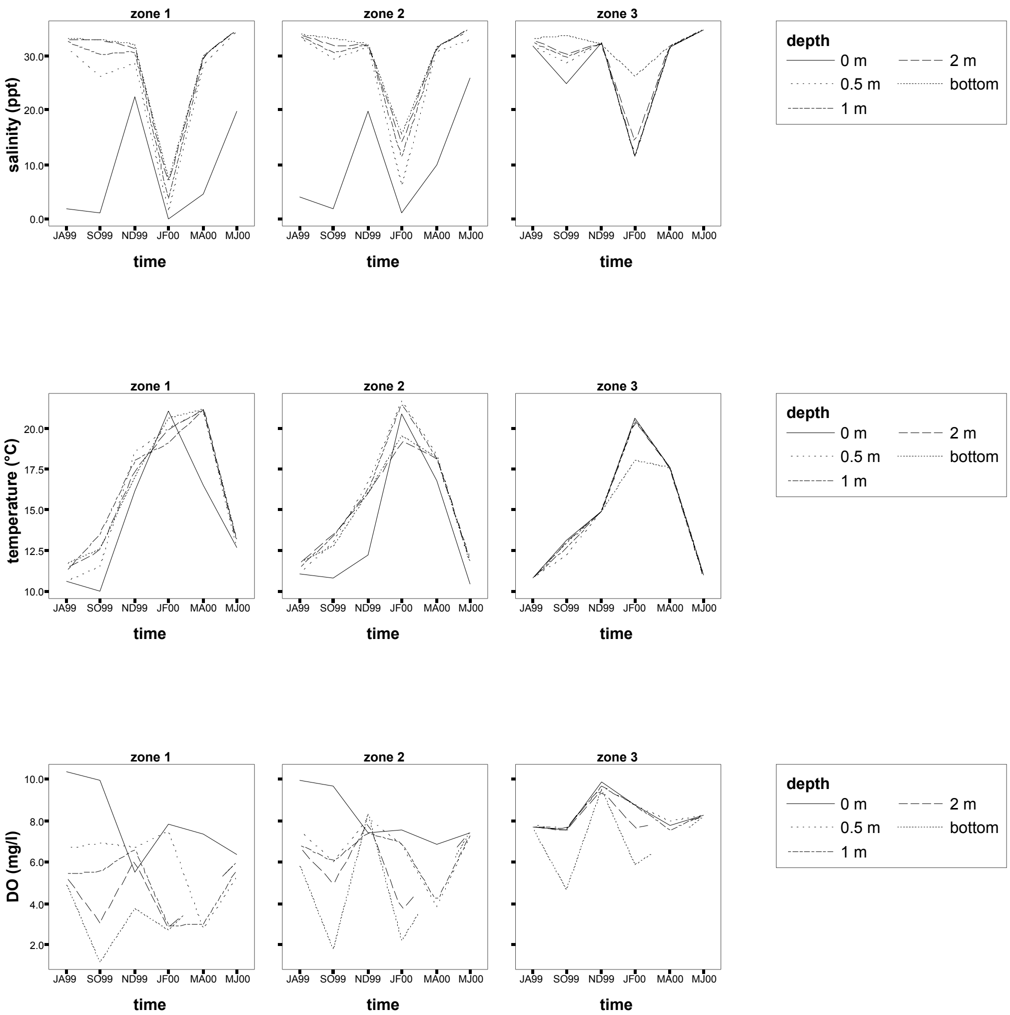

Fig. 19. Average salinity, temperature and DO, by zone and depth, Ansons Bay (Jul/Aug 99 – May/Jun 00)

DO was highly variable by depth and zone. While surface waters were generally well oxygenated, reduced DO was recorded in bottom waters on most sampling occasions, particularly within zone 1 and 2. Differences of over 9 mg l^{-1} were recorded between surface and bottom waters (Fig. 19). Within the upper estuary, DO was regularly below 4 mg l^{-1} in bottom waters and was approximately 1 mg l^{-1} within zone 1 in September 1999. DO results for Ansons Bay demonstrate that for some parameters apparently healthy surface waters can overly 'unhealthy' (*i.e.* hypoxic) bottom water.

PCA poorly explained variation within the water quality data. The first component only accounted for 33 % of the variation and described a relationship between turbidity and suspended solids (Appendix 4).

Table 10 provides average values of water quality parameter, for each sampling occasion, in surface waters within Ansons Bay. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Chlorophyll *a* concentrations were generally high to very high particularly within zone 1 and 2, although, as can be seen from the large standard error values, this distribution was quite patchy (Table 10). Both the median (5.3 µg l^{-1}) and maximum (87.9 µg l^{-1}) were the highest recorded in any estuary during the study indicating that surface waters (at least) are eutrophic. In contrast, NO_x-N and turbidity was nearly always low throughout the estuary with medium level turbidity occurring after the flood event in January 2000. PO_4-P was of a medium concentration on most sampling occasions ranging from 2 to 25 µg l^{-1}. SiO_4-Si concentrations ranged from 110 to 1050 µg l^{-1}.

The data suggests that bottom water within the salt wedge in the upper estuary is highly susceptible to anoxic conditions. In the upper estuary, very low DO concentrations in bottom water in September 1999 were preceded by very high chlorophyll levels within surface waters. Surface waters had high to very high chlorophyll concentrations. This indicates that the 'river' section of Ansons Bay is relatively unhealthy, experiencing major algal blooms followed by anoxic bottom waters.

Table 10. Average values (n=6), yearly median and range (n= 36) for water quality parameters of surface waters, Ansons Bay (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	12.6 (14.9)	9.3 (12.1)	24.9 (6.9)	4.2 (5.7)	15.4 (12.9)	26.9 (10.6)	11.5	0.0	34.9
Temperature	°C	10.8 (0.2)	11.3 (1.5)	14.4 (2.3)	20.8 (0.3)	17.0 (0.5)	11.3 (1.1)	13.1	9.9	21.2
Dissolved O_2	mg l^{-1}	9.3 (1.3)	9.1 (1.2)	7.6 (2.0)	8.1 (0.6)	7.3 (0.4)	7.4 (1.0)	7.8	4.9	10.5
Turbidity	NTU	1.4 (0.9)	2.6 (1.5)	1.8 (0.2)	5.3 (2.7)	1.7 (0.3)	0.8 (0.2)	1.7	0.5	8.2
Chlorophyll *a*	µg l^{-1}	20.3 (33.5)	8.8 (8.3)	5.7 (1.8)	11.2 (10.4)	7.5 (4.0)	2.2 (4.0)	5.3	0.8	87.9
NO_x-N	µg l^{-1}	5 (4)	4 (3)	1 (1)	14 (5)	2 (0)	3 (4)	2	0	19
PO_4-P	µg l^{-1}	10 (6)	6 (2)	3 (0)	10 (4)	14 (7)	12 (6)	8	2	25
SiO_4-Si	µg l^{-1}	640 (220)	750 (200)	330 (190)	770 (190)	350 (190)	260 (90)	495	110	1050
Total SS	mg l^{-1}	6.6 (3.1)	11.5 (7.5)	15.0 (6.4)	5.8 (1.1)	4.5 (1.6)	5.5 (6.0)	6.4	109	26.2
Volatile SS	mg l^{-1}	2.7 (2.1)	3.4 (1.5)	4.1 (1.5)	2.3 (0.4)	1.9 (0.6)	1.7 (1.0)	2.1	0.8	6.9
Fixed SS	mg l^{-1}	3.8 (1.9)	8.2 (6.1)	10.9 (5.0)	3.5 (1.2)	2.6 (1.1)	3.8 (5.1)	4.1	0.6	20.1

3.1.10 Grants Lagoon

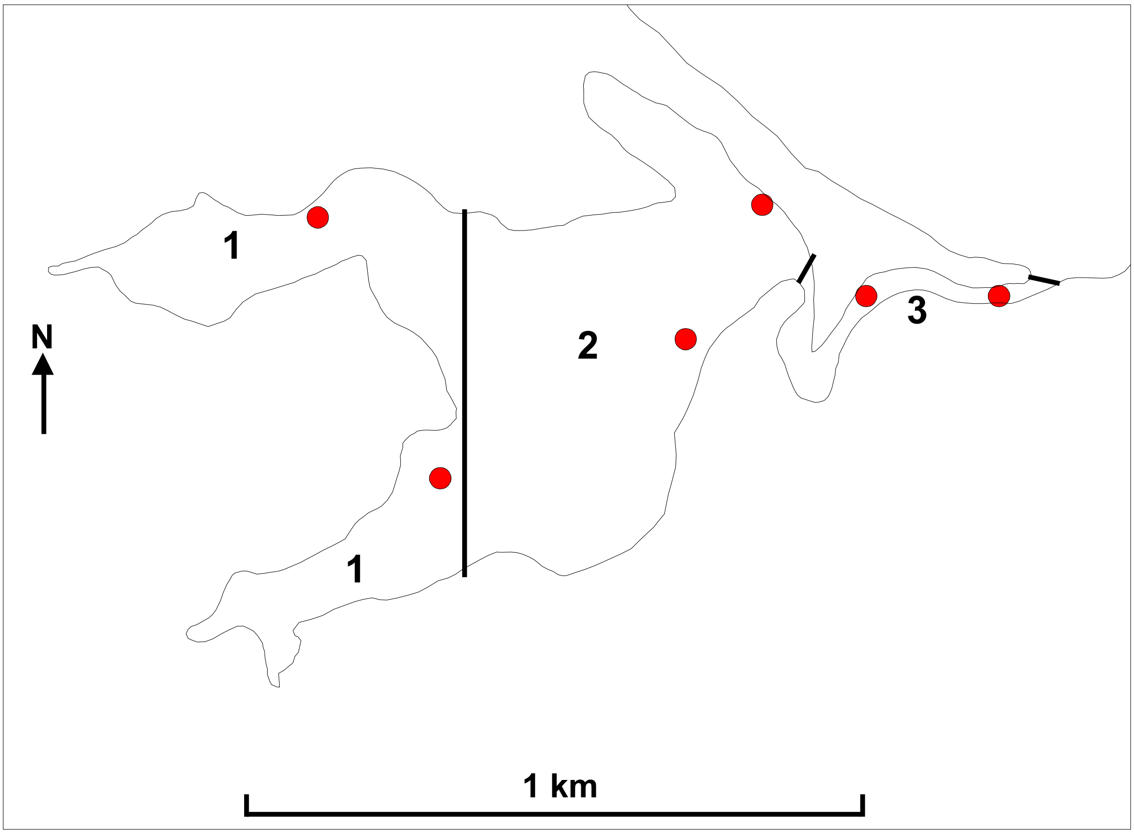

Fig. 20. Grants Lagoon showing fixed sampling sites and zones.

Grants Lagoon is a barred low-salinity estuary (Edgar *et al.* 1999), the usual state being a closed coastal lagoon. Because the estuary is rarely open, it is not generally tidal. The bar was closed for the duration of the study. Within zone 1 and 2, the estuary consists of an enclosed lagoon that is approximately 1 to 3 m in depth. Zone 3 is a narrow 'backwater' of just over 1 m in depth. Edgar *et al.* (1999) identified Grants Lagoon as being of moderate conservation significance. The National Land and Water Resources Audit identified Grants Lagoon as being a modified, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

The patterns of salinity over time within the zones were not consistent by depth (Appendix 3). However, Fig. 21 shows the general pattern for the estuary is to be well mixed, with no difference in salinity between the surface and the bottom. Salinity was usually identical within zones 1 and 2, with the salinity in zone 3 being approximately 0.5 ppt less than in the other zones. The exception to this was November 1999 when it was 0.5 ppt higher in zone 3. However, zones 1 and 2 became stratified following the extreme rain event of January 2000. Over the study period, the average salinity between zones ranged from 20.9 to 27.7 ppt.

There was weak evidence that the patterns of temperature over time within the zones were not consistent by depth (although T*Z*D Pillia's trace for the multi-variate test, P

= 0.579) (Appendix 3). As for salinity, Fig. 21 shows that generally there was no thermal stratification within the estuary and very little difference in temperature between zones 1 and 2. The exception to this was after the January 2000 flood event when a difference of almost 5 °C was recorded between the surface and bottom within zone 1 and 2. Except for this anomaly, there was less than 0.5 °C difference by depth within zones 1 and 2 on the other sampling occasions. Average temperatures by depth recorded within the main part of the lagoon ranged from10.1 to 23.8 °C. Zone 3 showed no difference in temperature by depth, except for January 2000 when surface waters were approximately 1 °C higher than the bottom. The temperature within zone 3 was up to 2 °C different to that recorded within the rest of the lagoon on some sampling occasions. Temperature within zone 3 ranged from 9.6 to 23.8 °C.

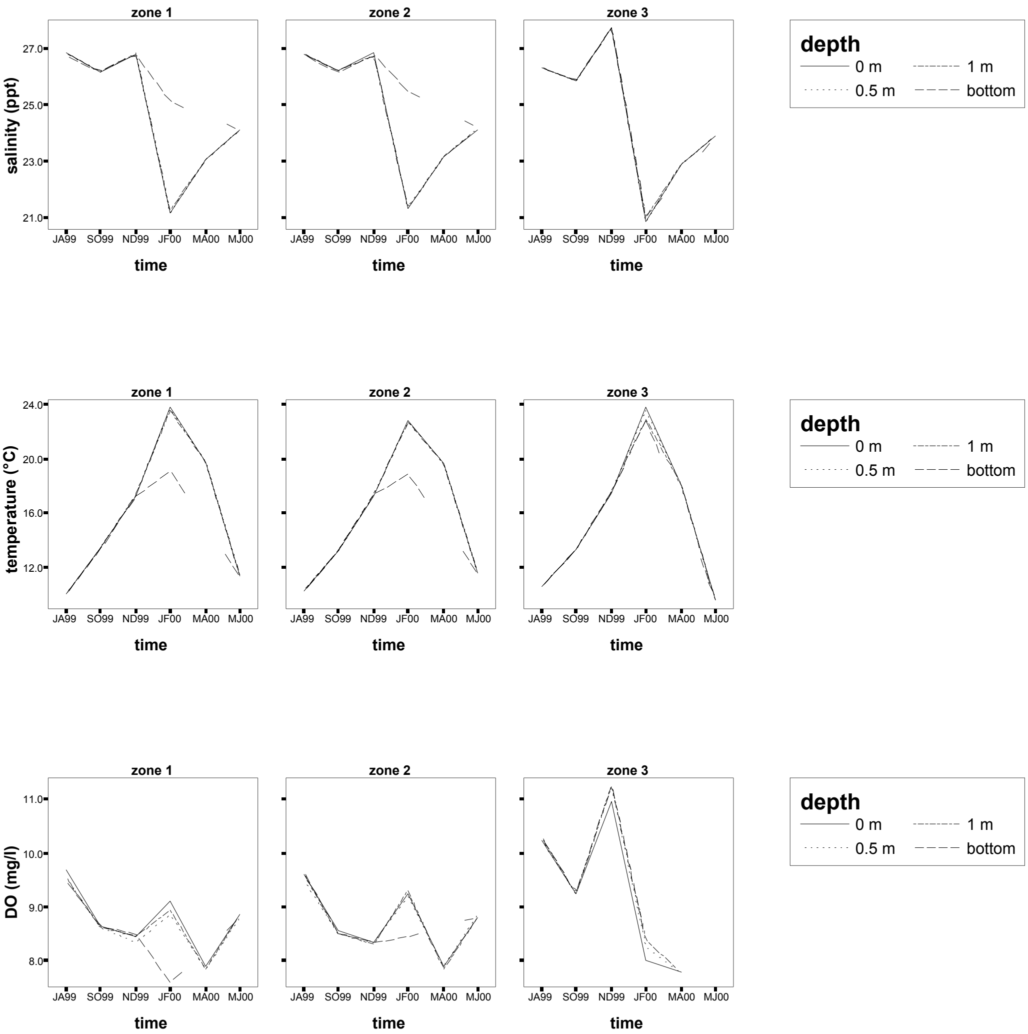

Fig. 21. Average salinity, temperature and DO, by zone and depth, for Grants Lagoon (Jul/Aug 99 – May/Jun 00)

Table 11. Average values (n=6), yearly median and range (n= 36) water quality parameters of surface waters, Grants Lagoon (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	26.6 (0.3)	26.1 (0.2)	27.1 (0.5)	21.1 (0.2)	23.0(0.1)	24.0 (0.1)	24.9	20.8	27.9
Temperature	°C	10.4 (0.3)	13.3 (0.1)	17.4 (0.2)	23.4 (0.5)	19.1(0.9)	10.9 (1.0)	15.4	9.5	23.9
Dissolved O_2	mg l^{-1}	9.9 (0.3)	8.8 (0.4)	9.3 (1.4)	8.8 (0.8)	7.9(0.3)	8.8 (0.1)	8.8	7.4	11.8
Turbidity	NTU	1.2 (0.3)	1.3 (0.2)	2.7 (1.1)	2.2 (0.4)	1.7(0.3)	1.2 (0.4)	1.5	0.6	4.3
Chlorophyll *a*	µg l^{-1}	1.3 (0.7)	1.0 (0.6)	0.4 (0.3)	3.0 (0.2)	1.2 (0.6)	0.8 (0.6)	1.2	0.0	3.3
NO_x-N	µg l^{-1}	17 (8)	3 (6)	0 (0)	1 (0)	2 (1)	38 (12)	1	0	48
PO_4-P	µg l^{-1}	4 (3)	2 (0)	3 (0)	3 (1)	2 (0)	2 (1)	2	2	9
SiO_4-Si	µg l^{-1}	40 (30)	40 (10)	40 (30)	590 (30)	50 (30)	40 (30)	60	0	630
Total SS	mg l^{-1}	4.6 (0.8)	19.1 (3.2)	4.2 (1.0)	5.8 (1.3)	3.1 (0.6)	2.6 (0.9)	4.5	1.0	25.4
Volatile SS	mg l^{-1}	1.4 (0.3)	3.7 (1.1)	1.7 (0.4)	2.2 (0.4)	1.5 (0.2)	1.6 (0.5)	1.7	1.0	5.4
Fixed SS	mg l^{-1}	3.2 (0.9)	15.4 (2.3)	2.5 (0.6)	3.5 (1.0)	1.7 (0.4)	1.0 (1.2)	2.9	0	20.0

There was weak evidence that the patterns of DO within the zones were not consistent over time (although T*Z Pillia's trace for the multi-variate test, P = 0.282) (Appendix 3). Fig. 21 shows that, except for January 2000, there was very little difference between zones 1 and 2, or by depth, within these zones, the greatest difference being 0.2 mg/l on any sampling occasion. Average DO over time was also reasonably constant within these zones, ranging from 7.9 to 9.7 mg/l for any depth and sampling event. However., during January 2000, the surface DO was up to 1.5 mg/l greater than on the bottom within the main part of the estuary. Average DO within zone 3 showed a greater variability over time than within the other zones, ranging from 7.8 to 11.3 mg/l for any depth and sampling event. Within zone 3, surface and bottom DO differences were always less than 0.5 mg/l.

The first component of PCA of water quality data only described 32 % of the variation in the data and described temperature, chlorophyll and SiO_4-Si having a negative relationship with salinity. The second component described a correlation between the suspended solids and accounted for 28 % of the variation (Appendix 4).

Table 11 provides average values of water quality parameter, for each sampling occasion, in surface waters within Grants Lagoon. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Except for during extreme rain events, conditions monitored in surface waters are likely to be representative of all depths within Grants Lagoon. The level of the main water quality parameters was generally low on all sampling occasions, suggesting that Grants Lagoon is a relatively healthy estuary. The median value recorded for turbidity was 1.5 NTU while median chlorophyll, NO_x-N and PO_4-P concentrations were 1.2, 1 and 2 µg l^{-1}, respectively.

3.1.11 Douglas River

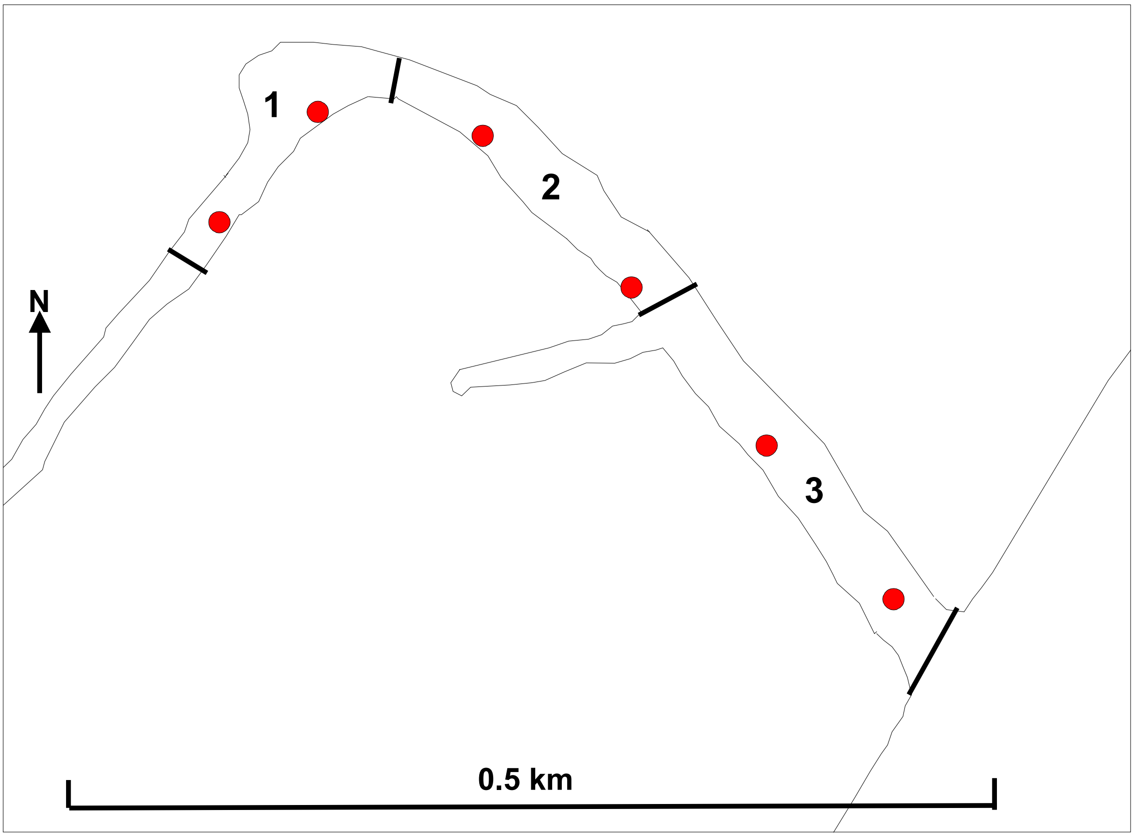

Fig. 22. Douglas River showing fixed sampling sites and zones.

The Douglas River is an open estuary (Edgar *et al.* 1999). Except for May 2000, when a sand barrier had formed at the mouth of the estuary, the estuary was open on all other sampling occasions. The estuary is a relatively narrow river of approximately 2-3 m depth within zones 2 and 3. Zone 1 is approximately 1 m in depth. The incursion of a salt wedge above zone 1 is usually constrained by a small rocky barrier. However, anecdotal evidence suggests that when the estuary is intermittently closed, continued river flow combined with the sand barrier can result in saline water moving further upstream past this barrier. Edgar *et al.* 1999 identified the Douglas River estuary as being of moderate conservation significance. The National Land and Water Resources Audit identified the Douglas River estuary as being a largely unmodified, wave dominated estuary (NLWRA 2002).

The pattern of salinity over time within the zones was not consistent by depth (Appendix 3). Fig. 23 shows that the estuary was always distinctly stratified, the halocline occurring above and below the 0.5 m depth on different sampling occasions. Average surface salinity was always less than 2 ppt, except for when the estuary was closed when the surface salinity maximum of 14.5 ppt was recorded. Average bottom salinity within the estuary ranged from 24.3 to 29 .5 ppt and was most variable within zone 1.

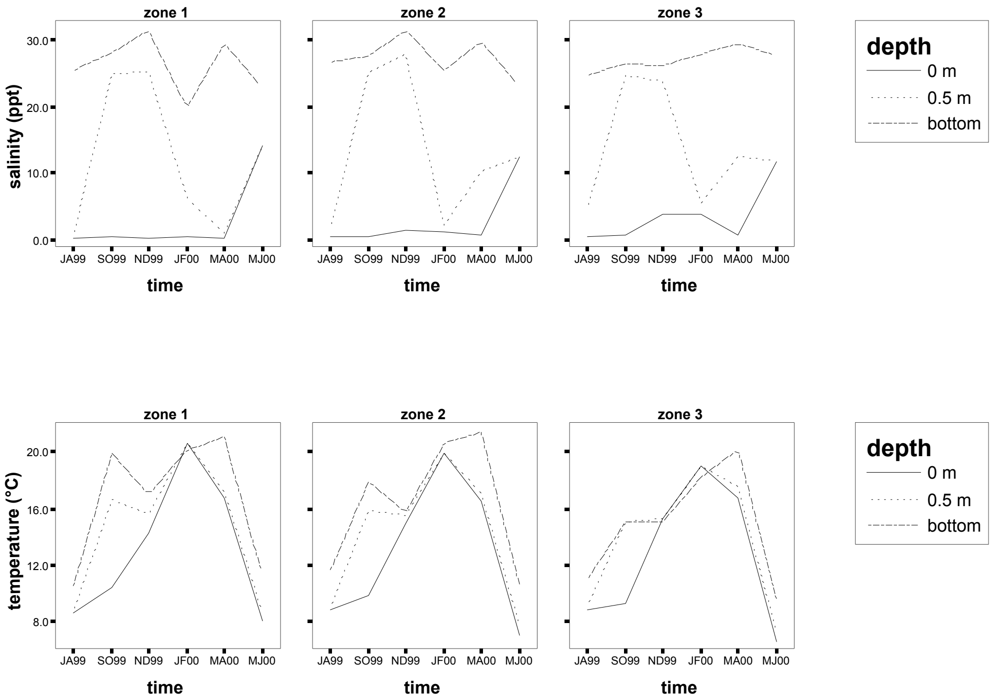

Fig. 23. Average salinity and temperature, by zone and depth, Douglas River (JA99 – MJ00)

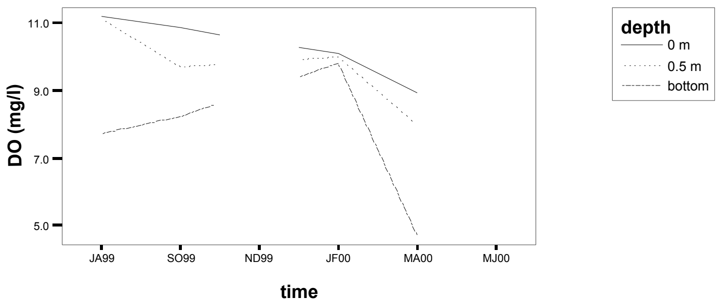

Fig. 24. Average surface DO, by depth, Douglas River (JA99 – MJ00)

The patterns of temperature over time were not consistent by either zone or depth (Appendix 3). Fig. 23 shows that the similar temperature profiles usually occurred within zone 1 and 2 and that the average temperature at all depths tended to be lower in zone 3 than the other two zones. The difference between average surface and bottom temperatures was relatively large on several sampling occasions, the largest recorded difference being almost 10 °C within zone 1 during September 1999. The minimum and maximum temperatures recorded within the estuary were 6.5 and 20.9 °C and 7.9 and 22.0 °C, for the surface and bottom, respectively.

Table 12. Average values (n=6), yearly median and range (n= 30 or 36) for water quality parameters of surface waters, Douglas River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	Units	JA 99	SO 99	ND 99	JF 00	MA 00	MJ 00	99 / 00	Min	Max
Salinity	ppt	0.4 (0.1)	0.5 (0.2)	1.9 (2.2)	1.8 (1.6)	0.6(0.2)	12.8 (1.2)	0.7	0.1	14.5
Temperature	°C	8.7 (0.2)	9.8 (0.5)	14.8 (0.5)	19.8 (0.7)	16.7(0.2)	7.2 (0.7)	12.3	6.5	20.9
Dissolved O_2	mg l^{-1}	11.2 (0.5)	10.8 (0.2)	13.2 (0.8)	10.1 (0.9)	8.9(1.1)		10.8	7.7	14.1
Turbidity	NTU	8.0 (0.2)	1.4 (0.2)	1.6 (0.6)	2.1 (0.3)	1.4(0.2)	2.1 (0.8)	1.7	1.1	8.3
Chlorophyll *a*	µg l^{-1}	0.1 (0.2)	1.0 (0.4)	0.7 (1.1)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0	0.0	3.0
NO_x-N	µg l^{-1}	11 (2)	0 (0)	11 (4)	178 (33)	75 (16)	62 (18)	24	0	220
PO_4-P	µg l^{-1}	1 (0)	2 (1)	2 (1)	3 (2)	2 (1)	8 (4)	2	1	13
SiO_4-Si	µg l^{-1}	5150 (170)	2440 (830)	2040 (720)	7160 (620)	6230 (910)	3930 (1060)	4765	1030	8050
Total SS	mg l^{-1}	2.2 (0.5)	4.3 (1.4)	67.4 (145.2)	2.4 (1.2)	3.1 (0.8)	2.9 (1.0)	2.9	1.3	363.4
Volatile SS	mg l^{-1}	0.6 (0.1)	1.2 (0.3)	2.8 (4.1)	0.8 (0.2)	0.6 (0.2)	1.2 (0.2)	0.9	0.4	11.0
Fixed SS	mg l^{-1}	1.6 (0.4)	3.1 (1.1)	64.6 (141.1)	1.6 (1.0)	2.6 (0.6)	1.6 (0.9)	2.3	0.6	352.4

For DO concentrations, there was no zone effect but the pattern of over time was not consistent by depth (Appendix 3). DO was consistently higher on the surface (Fig. 24), although it should be noted that DO was only recorded on four sampling occasions. During sampling, the average DO ranged from 8.9 to 11.2 mg/l on the surface and 4.7 to 9.8 mg/l on the bottom. The largest difference recorded between the surface and bottom was over 4 mg/l in March 2000.

The first component of PCA accounted for 42% of the data and described suspended solids and chlorophyll having a negative relationship with SiO_4-Si and NO_x-N. The second component, describing 25 % of the data, consisted of temperature and PO_4-P having a negative correlation with turbidity (Appendix 4).

Table 12 provides average values of water quality parameter, for each sampling occasion, in surface waters within the Douglas River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given. However, because of the stratified nature of the Douglas River estuary, water quality parameters measured from surface waters are unlikely to be representative of conditions below approximately 0.5 m in depth.

Generally, the level of most water quality indicators was low with median values for turbidity, chlorophyll and PO_4-P being 1.7 NTU, 0 and 2 µg l^{-1}, respectively. In contrast, NO_x-N concentrations were very low in the first three sampling occasions but were very high (median of 178 µg l^{-1}) following the large flood event in January 2000 and high in the two subsequent samples. SiO_4-Si concentrations in surface waters were consistently the highest of all estuaries in the study, ranging from 1030 to 8050 µg l^{-1} with a median value of 4765 µg l^{-1}.

3.1.12 Great Swanport

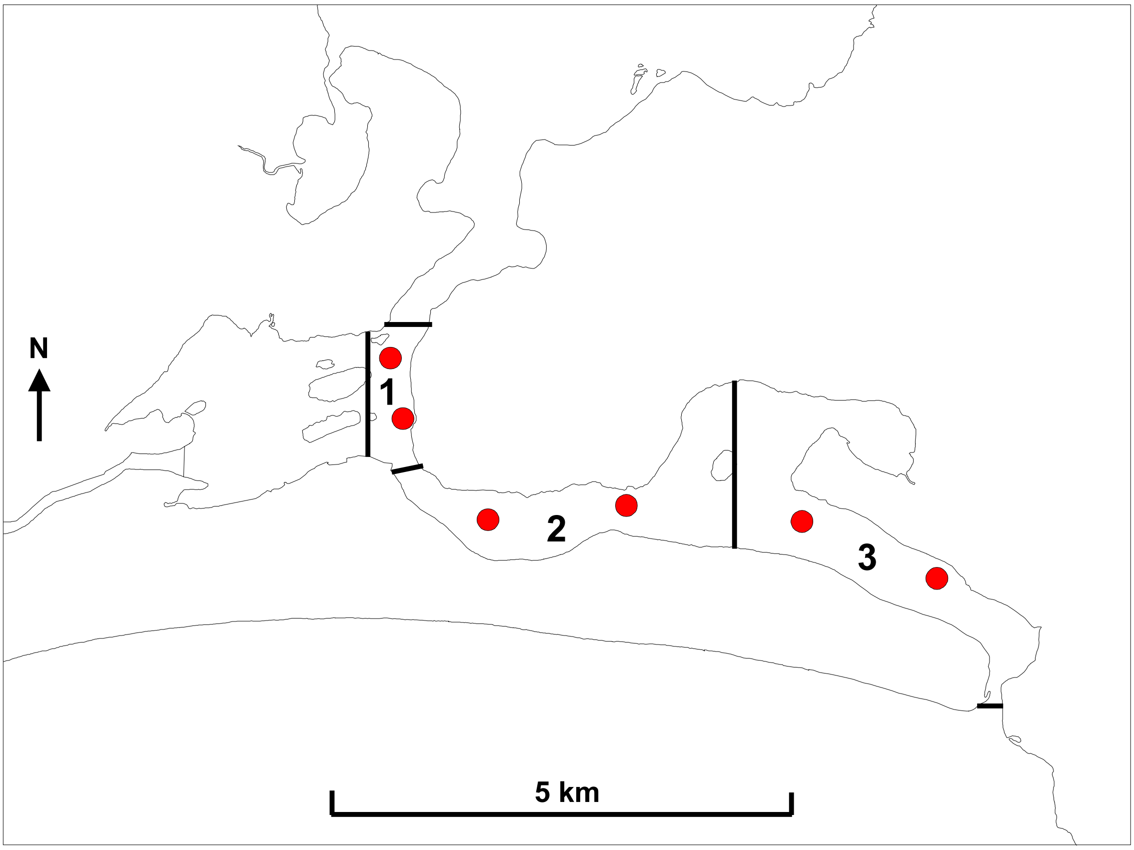

Fig. 25. Great Swanport showing fixed sampling sites and zones.

Great Swanport is an open estuary (Edgar *et al.* 1999) with a distinct channel of 2-3 m depth occurring within zone 3 and the lower reaches of zone 2. Within zone 1 and on either side of the main channel, the estuary is relatively shallow being approximately 1 m at low tide. Edgar *et al.* (1999) identified Great Swanport as being of high conservation significance. The National Land and Water Resources Audit identified Great Swanport as being a near pristine, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

For salinity, a significant interaction between time and zone was recorded but there was no effect by depth (Appendix 3). Salinity was consistently highest at the mouth of the estuary, zone 3, and was generally at least 2 ppt greater within this zone than within zone 1. The exception to this was May 2000 when the difference was only 0.5 ppt. In September 1999, salinity at the mouth of the estuary was over 5 ppt higher than within zone 1 (Fig. 26). Average salinity was relatively constant within zone 3, ranging between 34.6 and 35.7 ppt over the sampling period. Salinity was most variable over time within zone 1 ranging between 29.5 and 35 .2 ppt.

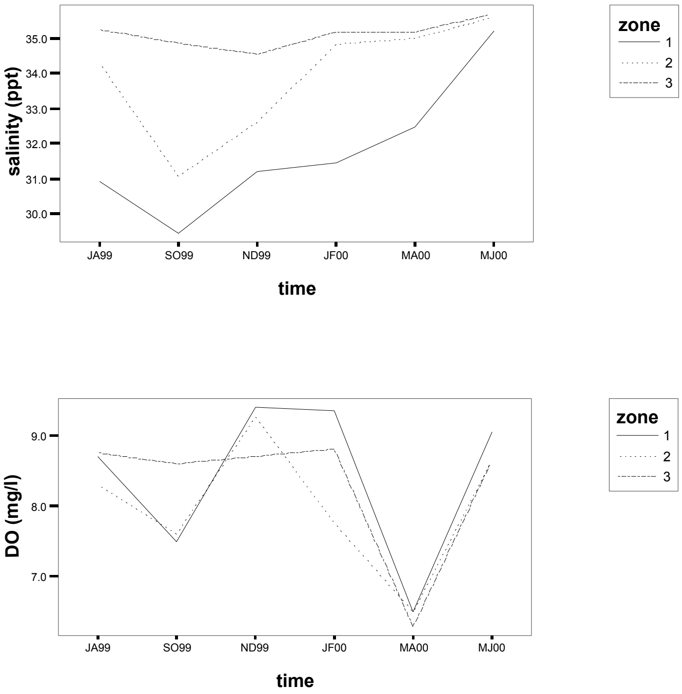

Fig. 26. Average surface salinity and DO, by zone, Great Swanport (JA99 – MJ00)

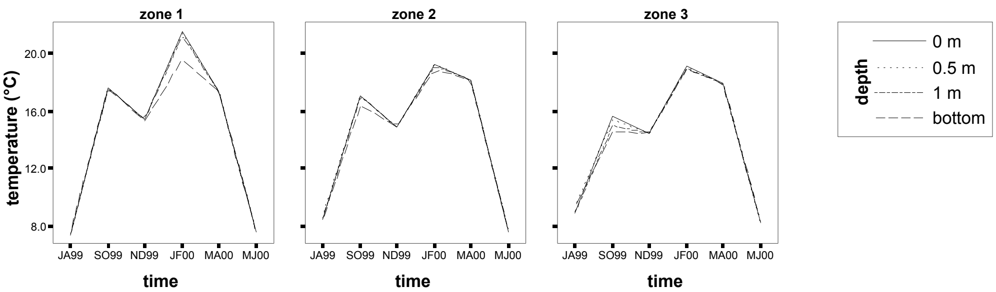

Fig. 27. Average temperature, by zone and depth, Great Swanport (JA99 – MJ00).

There was some weak evidence that the patterns of temperature over time within the zones were not consistent by depth (although T*Z*D Pillia's trace for the multi-variate test, P=0.287). Fig. 27 shows that, in general, there was very little difference in temperature by depth within zones, being with 0.5 °C between the surface and bottom on most sampling occasions. The largest difference was less than 2 °C, within zone 1 in January 2000. Average temperatures within the zones ranged from 7.4 to 21.6 °C.

For DO, a significant interaction occurred between time and zone but there was no depth effect (Appendix 3). Average DO between zones was generally within 1.5 mg l^{-1} during any sampling event. DO concentrations ranged between 6.0 and 10.5 mg l^{-1} and were lowest during March 2000 (Fig. 27).

Table 13. Average values (n=6), yearly median and range (n= 36) for water quality parameters of surface waters, Great Swanport (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	33.5 (2.1)	31.8 (2.5)	32.8 (1.5)	33.8 (2.0)	34.2 (1.6)	35.5 (0.3)	34.6	29.3	35.7
Temperature	°C	8.2 (0.7)	16.8 (0.9)	14.9 (0.5)	20.0 (1.3)	17.8 (0.4)	7.8 (0.4)	15.5	7.1	21.8
Dissolved O_2	mg l^{-1}	8.6 (0.3)	7.9 (0.6)	9.1 (0.5)	8.6 (0.9)	6.4 (0.2)	8.8 (0.2)	8.6	6.1	9.9
Turbidity	NTU	1.7 (0.9)	1.5 (0.5)	1.6 (0.3)	1.5 (0.7)	1.4 (0.2)	1.8 (0.7)	1.4	1.0	3.4
Chlorophyll *a*	µg l^{-1}	0.3 (0.3)	0.4 (0.4)	0.1 (0.2)	0.9 (0.5)	0.6 (0.1)	1.0 (0.7)	0.5	0.0	2.2
NO_x-N	µg l^{-1}	0 (0)	2 (1)	0 (1)	2 (1)	1 (0)	0 (0)	1	0	4
PO_4-P	µg l^{-1}	6 (2)	3 (1)	2 (1)	4 (1)	5 (1)	2 (1)	3	2	8
SiO_4-Si	µg l^{-1}	130 (110)	90 (50)	190 (80)	120 (90)	80 (30)	40 (10)	75	30	310
Total SS	mg l^{-1}	12.8 (11.1)	4.4 (1.4)	4.2 (1.2)	6.3 (1.3)	5.0 (0.7)	6.1 (2.1)	5.0	2.4	29.3
Volatile SS	mg l^{-1}	2.7 (1.6)	1.3 (0.3)	1.3 (0.3)	1.0 (0.3)	1.1 (0.1)	1.6 (0.5)	1.3	0.6	5.2
Fixed SS	mg l^{-1}	10.2 (9.6)	3.1 (1.1)	2.9 (0.9)	5.3 (1.0)	3.9 (0.6)	4.5 (1.6)	3.8	1.4	24.1

The first component of PCA described a relationship between turbidity and suspended solids and accounted for only 34 % of the variation in the data. The second component described a correlation between temperature and NO_x-N and accounted for 22 % of the variation in the data (Appendix 4).

Table 13 provides average values of water quality parameter, for each sampling occasion, in surface waters within Great Swanport. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

The generally unstratified nature of Great Swanport indicates that surface waters are likely to be representative of conditions at all depths. The level of the main water quality parameters was low on all sampling occasions indicating that Great Swanport is a relatively healthy estuary. The median value recorded for turbidity was 1.4 NTU while median chlorophyll *a*, NO_x-N and PO_4-P concentrations were 0.5, 1 and 3 µg l^{-1}, respectively.

3.1.13 Meredith River

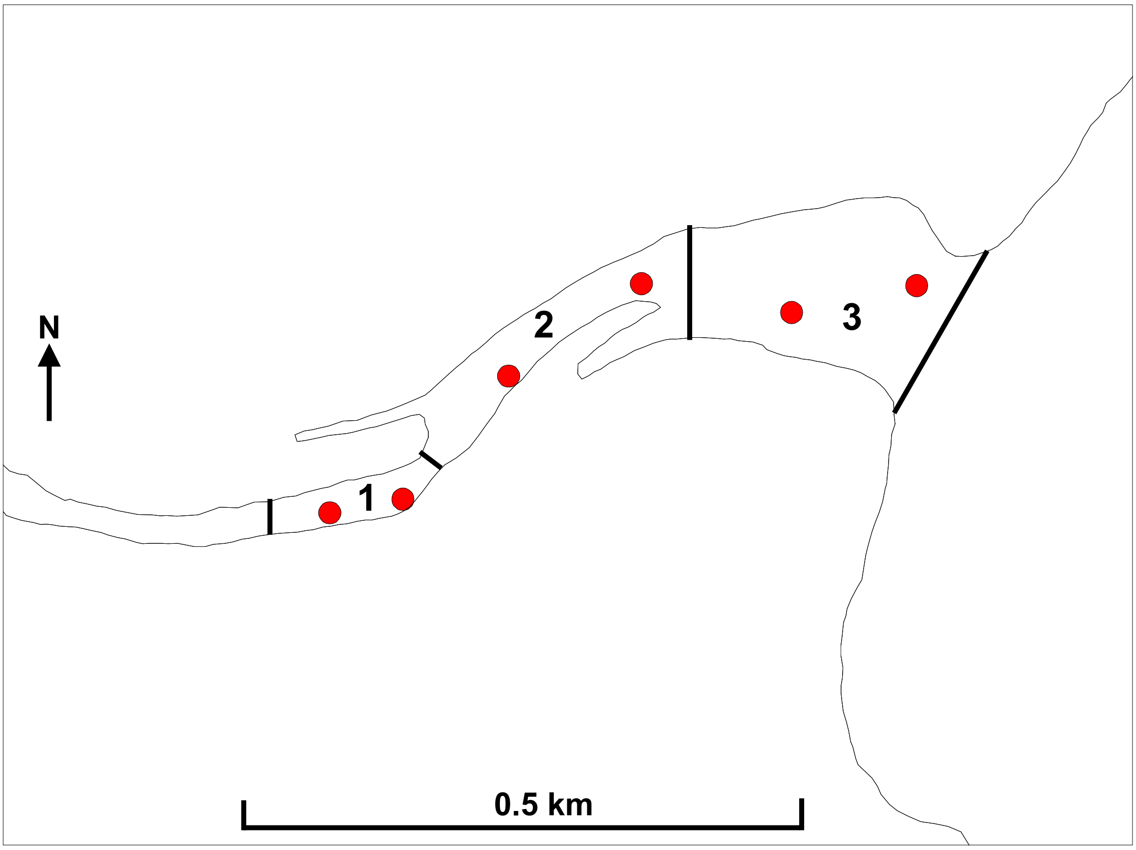

Fig. 28. Meredith River showing fixed sampling sites and zones.

The Meredith River estuary is a barred, low-salinity estuary (Edgar *et al.* 1999). At low tide, the lower estuary is generally less than 1 m deep in zone 3 and approximately 1-2 m in depth within zone 1 and 2. The estuary was closed on three of the six sampling occasions; September 1999, and March and May 2000. In addition, the estuary was closed on one (May 1999) of two preliminary surveys conducted in early 1999. When the estuary was closed, depths within the estuary increased by approximately 1 m. Edgar *et al.* (1999) identified the Meredith River estuary as being of low conservation significance. The National Land and Water Resources Audit identified the Meredith River estuary as being a modified, river dominated estuary (subclass: wave delta) (NLWRA 2002).

The pattern of salinity within the zones was not consistent by depth (Appendix 3) and was highly variable throughout the estuary (Fig. 29). Within zone 1, average values ranged from 0.4 to 28.2 ppt on the surface and 13.0 to 34.3 ppt on the bottom. On some sampling occasions, surface salinity in this zone was almost 15 ppt lower than on the bottom. Within zone 2, average surface salinity ranged from 0.9 to 28.2 ppt and bottom salinity was between 25.5 and 35.0 ppt. Surface salinity in zone 2 was up to 30 ppt less than on the bottom on some sampling occasions. The average surface salinity in zone 3 ranged from 2.1 to 31.8 ppt and bottom salinity was between 28.1 and 33.6 ppt. While the difference between salinity in surface and bottom waters was generally not as great as in the upper estuary, a difference of almost 27 ppt was recorded on one sampling occasions.

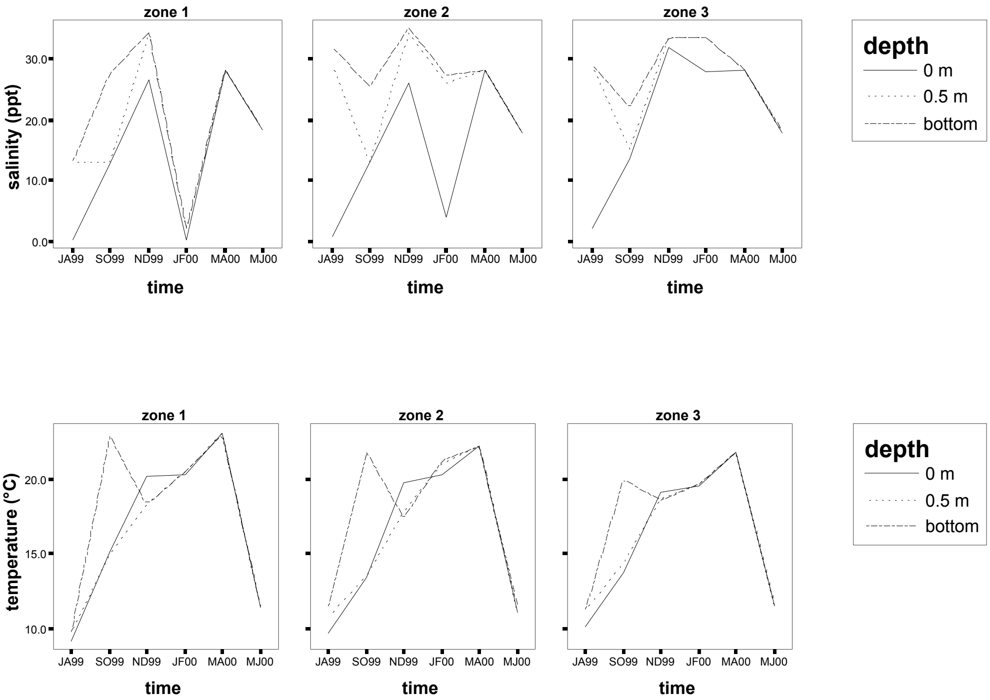

Fig. 29. Average salinity and temperature, by zone and depth, Meredith River (JA99 – MJ00).

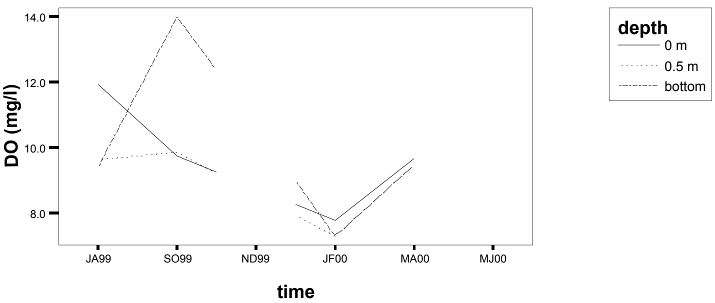

Fig. 30. Average DO by depth, Meredith River (JA99 – MJ00)

The patterns of temperature over time were not consistent by zone or depth, and there was weak evidence that the behaviour over time in the zones was inconsistent over depth (although T*Z*D Pillia's trace for the multi-variate test, P = 0.302) (Appendix 3). Fig. 29 shows that the pattern of temperature was somewhat similar between zones, but that a slightly greater range of temperatures was experienced in the upper estuary. Within the zones, average surface temperature ranged from 9.1 to 23.2 °C and average bottom temperature from 9.7 to 23.1 °C. The difference between surface and bottom temperature was generally less than 2°C, but a maximum difference of over 8 °C was recorded on one occasion.

The pattern of DO by depth was inconsistent over time but there was no zone effect (Appendix 3). Average values by depth ranged from 7.8 to 14.0 mg/l, with differences of over 4 mg/l between surface and bottom waters being record on one sampling occasion (Fig. 30).

The first component of PCA accounted for 45 % of variation within the data and described a positive relationship between suspended solids, chlorophyll a and PO_4-P. The second component indicated a negative relationship between salinity and turbidity and accounted for 29 % of variation in the data (Appendix 4).

Table 14 provides average values of water quality parameter, for each sampling occasion, in surface waters within the Meredith River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Water parameters measured at the surface are unlikely to be representative of conditions within bottom water in the Meredith River estuary. However, the main water quality parameters suggest that the estuary is moderately impacted. NO_x-N concentrations were high to very high on some sampling occasions and chlorophyll *a* levels were generally medium to high suggesting the system is eutrophic. Although the median for NO_x-N was only 6 µg l^{-1}, a maximum value of 203 µg l^{-1} was recorded with the very high values restricted to zone 1. Standard error values for chlorophyll (Table 14) indicate that concentrations recorded throughout the estuary were generally highly variable with no obvious trend by zone. Although the median chlorophyll value was only 1.9 µg l^{-1}, a maximum of 30.7 µg l^{-1} was recorded. Turbidity was low on all sampling occasions, the exception being July 1999 when high turbidity was associated with low surface salinity. The median PO_4-P concentration of 2 µg l^{-1} was low. SiO_4-Si was highly variable within the estuary and between sampling occasions, recorded concentrations ranging from 0 to 8180 µg l^{-1} (the highest maximum value recorded during the study).

Table 14. Average values (n=6), yearly median and range (n= 24 or 36) for water quality parameters of surface waters, Meredith River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	1.1 (0.8)	13.1 (0.4)	28.1 (2.9)	10.7 (14.1)	28.1 (0.2)	18.0 (0.3)	17.9	0.1	35.1
Temperature	°C	9.6 (0.4)	14.1 (0.9)	19.8 (0.5)	20.1 (0.4)	22.5 (0.6)	11.3 (0.2)	17.2	9.1	23.3
Dissolved O_2	mg l^{-1}	12.0 (1.4)	9.8 (0.6)		7.8 (1.4)	9.7 (1.4)		9.6	5.1	14.2
Turbidity	NTU	14.8 (5.1)	0.9 (0.1)	2.5 (1.0)	3.4 (1.1)	3.5 (0.6)	0.9 (0.1)	2.6	0.8	18.5
Chlorophyll *a*	µg l^{-1}	6.0 (12.1)	2.2 (1.1)	8.8 (8.6)	3.2 (3.1)	10.0 (3.4)	0.8 (0.1)	1.9	0.0	30.7
NO_x-N	µg l^{-1}	124 (74)	6 (6)	1 (2)	56 (62)	3 (5)	6 (4)	6	0	203
PO_4-P	µg l^{-1}	5 (3)	2 (1)	3 (1)	6 (5)	4 (1)	2 (0)	2	1	15
SiO_4-Si	µg l^{-1}	4600 (2560)	3310 (450)	290 (240)	3990 (3580)	0 (0)	290 (80)	550	0	8180
Total SS	mg l^{-1}	13.2 (9.9)	6.6 (3.4)	6.4 (2.0)	6.5 (5.0)	8.1 (1.5)	3.6 (0.9)	6.4	1.7	31.7
Volatile SS	mg l^{-1}	3.6 (3.2)	2.0 (0.7)	1.9 (1.0)	2.6 (1.7)	3.4 (0.6)	1.2 (0.2)	2.1	0.8	10.0
Fixed SS	mg l^{-1}	9.6 (6.8)	4.6 (2.8)	4.5 (1.2)	3.9 (3.3)	4.7 (1.0)	2.5 (0.7)	4.3	0.9	21.8

3.1.14 Little Swanport

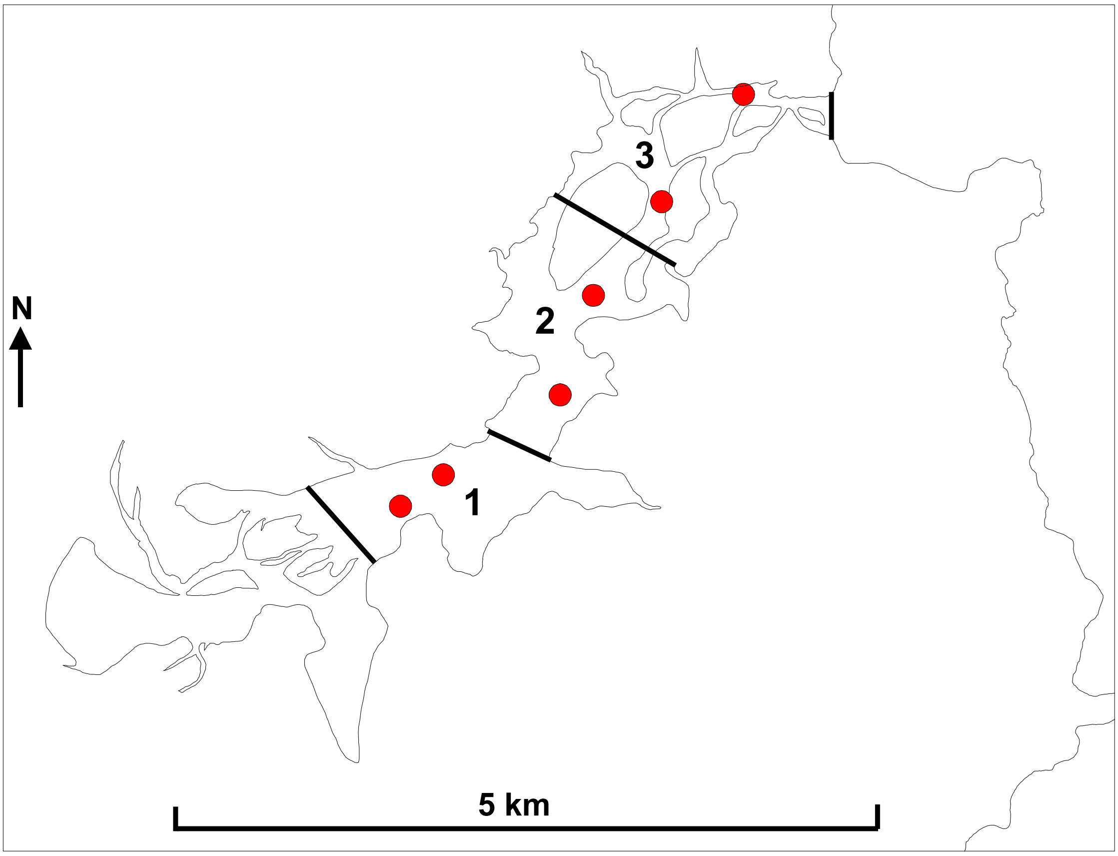

Fig. 31. Little Swanport showing fixed sampling sites and zones.

Little Swanport is an open estuary (Edgar *et al.* 1999) with an average depth of 2 to 4 m within zones 2 and 3 and 1 to 2 m zone 1. Edgar *et al.* (1999) identified Little Swanport as being of moderate conservation significance. The National Land and Water Resources Audit identified Little Swanport as being a modified, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

For salinity, a significant interaction occurred between time and zone (although T*Z Pillia's trace for the multi-variate test, P=0.244) but there was no depth effect (Appendix 3). Salinity ranged between 30.9 and 36.9 ppt, with a maximum difference of 2.2 ppt between zones during any one sampling event. Fig. 32 shows that salinity tended to be slightly higher at the head of the estuary during the first four sampling events, but this trend was reversed during March and May 2000 when zone 1 became hypersaline. The largest variation over time was within zone 1.

The patterns of temperature within the zones and by depth were not consistent over time although it can been seen from Appendix 3 that the evidence for depth was only weak (T*Z Pillia's trace for the multi-variate test, P=0.424). Figure Fig. 33 shows that there was very little difference in temperature by depth within zones, being with 0.5 °C between the surface and bottom on most sampling occasions. The largest difference was 2 °C within zone 2 in January 2000. Average temperatures within the zones ranged from 7.5 to 23.0 °C.

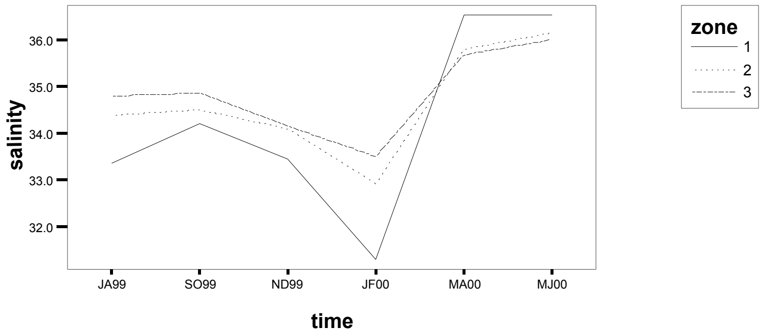

Fig. 32. Average salinity, by zone, Little Swanport (JA99 – MJ00)

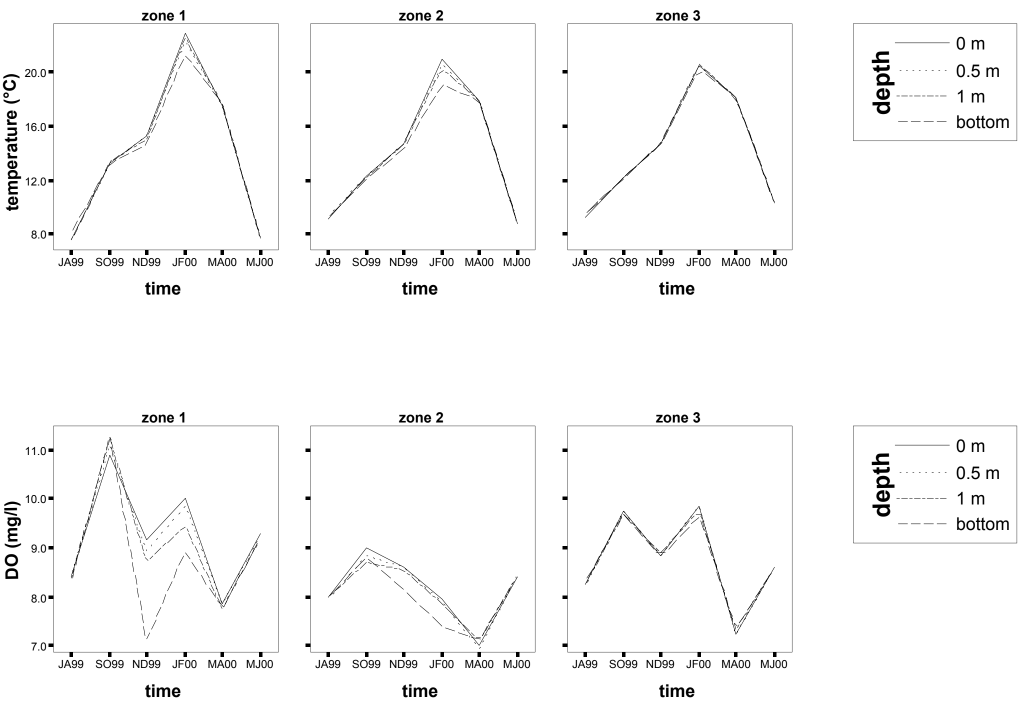

Fig. 33. Average temperature and DO, by zone and depth, Little Swanport (JA99 – MJ00)

Table 15. Average values (n=6), yearly median and range (n= 36) for water quality parameters of surface waters, Little Swanport (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	Units	JA 99	SO 99	ND 99	JF 00	MA 00	MJ 00	99 / 00	Min	Max
Salinity	ppt	34.2 (0.7)	34.5 (0.3)	33.9 (0.6)	32.6 (1.1)	36.0 (0.5)	36.2 (0.3)	34.5	30.9	36.9
Temperature	°C	8.6 (0.9)	12.6 (0.5)	14.9 (0.3)	21.5 (1.2)	17.9 (0.3)	8.9 (1.2)	14.0	7.5	23.4
Dissolved O_2	mg l^{-1}	8.2 (0.2)	9.9 (1.1)	8.9 (0.6)	9.3 (1.4)	7.4 (0.6)	8.8 (0.5)	8.5	6.9	11.4
Turbidity	NTU	1.8 (0.8)	1.5 (0.6)	2.1 (0.8)	2.3 (0.4)	3.3 (1.5)	2.1 (1.1)	1.8	0.8	6.2
Chlorophyll *a*	µg l^{-1}	0.7 (0.3)	0.3 (0.3)	1.2 (0.5)	2.4 (0.4)	6.1 (5.7)	1.1 (0.6)	1.1	0.1	17.8
NO_x-N	µg l^{-1}	3 (2)	1 (1)	0 (0)	0 (1)	0 (0)	2 (1)	0	0	5
PO_4-P	µg l^{-1}	6 (2)	4 (1)	3 (1)	3 (1)	5 (1)	4 (2)	4	2	7
SiO_4-Si	µg l^{-1}	80 (40)	100 (30)	120 (30)	180 (70)	60 (10)	70 (10)	90	30	280
Total SS	mg l^{-1}	20.4 (3.8)	7.5 (3.3)	8.6 (2.4)	14.6 (4.8)	9.7 (6.7)	6.4 (3.5)	8.6	3.7	26.2
Volatile SS	mg l^{-1}	3.2 (0.9)	1.5 (0.7)	2.3 (0.7)	3.4 (1.0)	2.6 (1.9)	1.4 (0.6)	2.2	1.0	6.6
Fixed SS	mg l^{-1}	17.2 (2.9)	5.9 (2.6)	6.3 (1.6)	11.3 (3.8)	7.0 (4.7)	5.0 (2.9)	6.5	2.7	21.8

The patterns of DO within the zones and by depth were not consistent over time although from Appendix 3 the evidence for depth was only weak (T*Z, P=0.466 for the uni-variate test). Figure Fig. 33 shows that, as for temperature, there was generally very little difference in DO by depth (particularly within zone 3). Recorded values were within 0.5 mg/l between the surface and bottom on most sampling occasions. Greater variation was observed in zone 1 with a difference of 2 mg/l between the surface and bottom being recorded in November 2000. Average DO within the zones ranged from 7.1 to 11.3 mg/l.

The first component of PCA described a positve relationship between the suspended solids, but accounted for only 34 % of the variation in the data. The second component was solely from NO_x-N values and accounted for 22 % of the variation in the data (Appendix 4).

Table 15 provides the average values of water quality parameters, for each sampling occasion, in surface waters within Little Swanport. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

The largely unstratified nature of Little Swanport indicates that on most occasions surface waters are likely to be representative of conditions at depth. The level of the main water quality parameters were generally low on most sampling occasions. However, chlorophyll concentrations were medium to high in January and March 2000, with a measurement of 17.8 µg l^{-1} recorded from the upper estuary in March 2000. The median value recorded for turbidity was 1.8 NTU while median, NO_x-N and PO_4-P concentrations were 0 and 4 µg l^{-1}, respectively. These results indicate that Little Swanport is a relatively healthy estuary but that chlorophyll levels may be elevated at certain times.

3.1.15 Earlham Lagoon

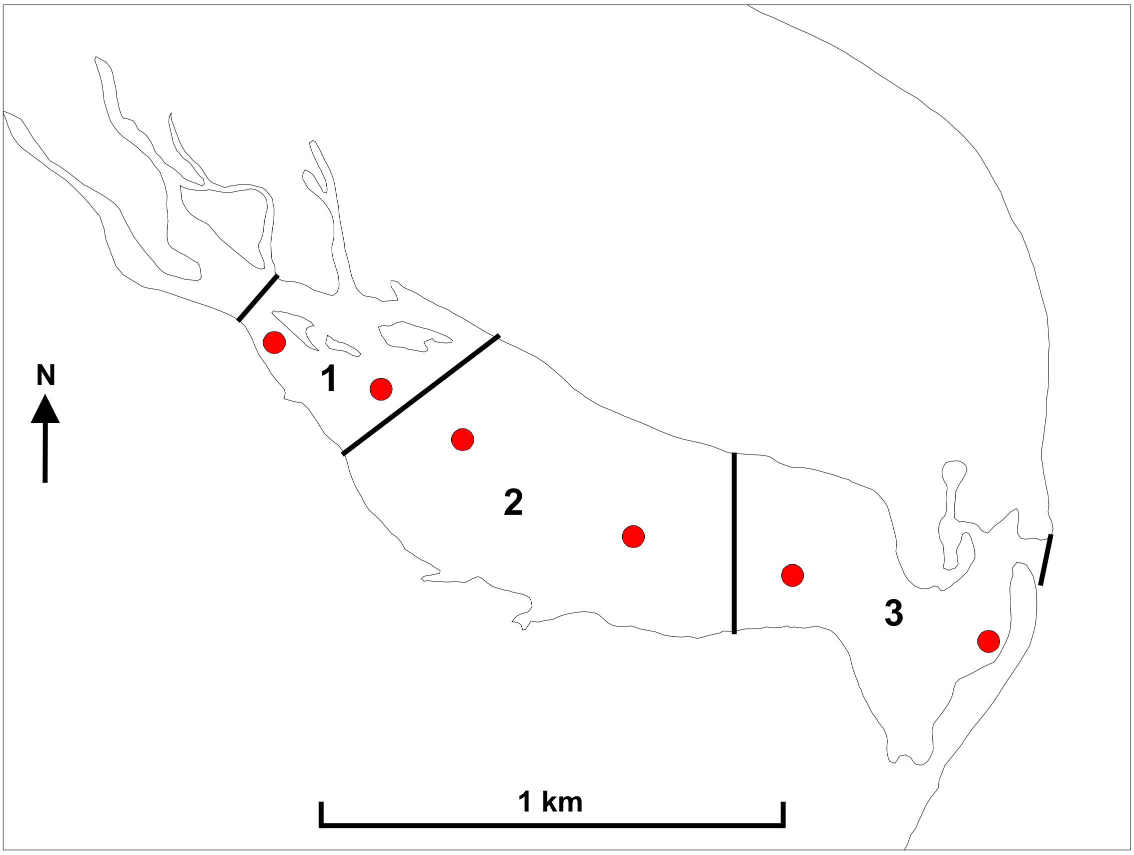

Fig. 34. Earlham Lagoon showing fixed sampling sites and zones.

Earlham Lagoon was classified as a hypersaline lagoon by Edgar *et al.* (1999). At low tide, the estuary consists of extensive sandflats on either side of a relatively narrow channel of less than 1 m in depth. Edgar *et al.* (1999) identified Earlham Lagoon as being of moderate conservation significance. The National Land and Water Resources Audit identified Earlham Lagoon as being a modified, tide dominated estuary (subclass: tide estuary) (NLWRA 2002).

There was weak evidence that the patterns of salinity over time were not consistent by either zone or depth (although T*Z, P=0.107 and T*D, P=0.079 for the uni-variate test) and there was a significant interaction between zone and depth (Appendix 3). Fig. 35 shows that the largest variation in salinity over both time and depth occurred within zone 1. Surface salinity ranged from 7.8 to 34.6 ppt and bottom salinity from 25.0 to 35.4 ppt. Although zone 1 was only strongly stratified on two occasions, the difference in salinity on these occasions was quite large, being up to 23 ppt different between the surface and bottom. There was very little difference in salinity by depth within zone 2 (which is generally less than 0.5 m deep at low tide) or zone 3. Average surface salinity ranged from 24.2 to 35.6 ppt in zone 2 and 28.3 to 35.7 ppt in zone 3. The maximum difference recorded between surface and bottom salinity within zone 3 was less than 4 ppt.

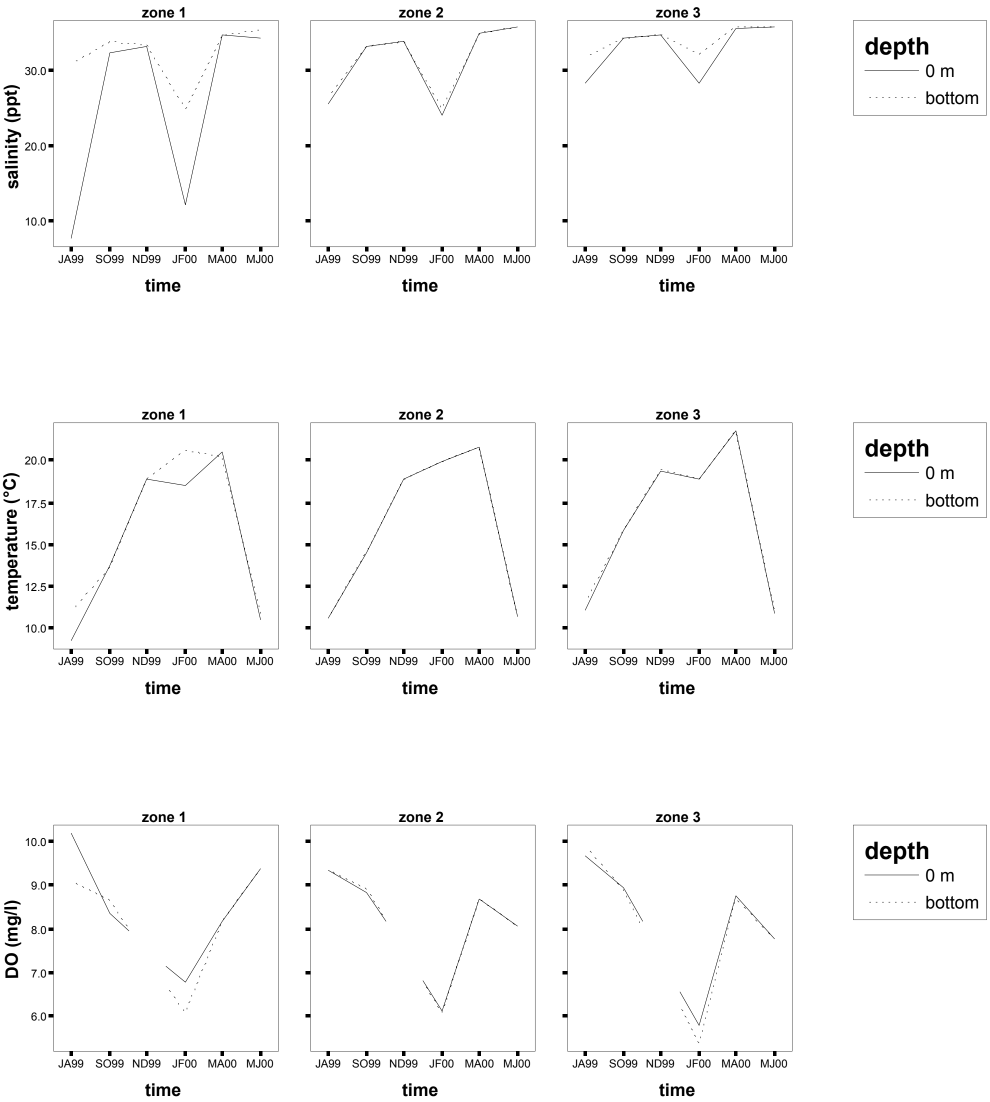

Fig. 35. Average salinity, temperature and DO, by zone and depth, Earlham Lagoon (JA99 – MJ00)

There was some weak evidence that the pattern of temperature over the zones was not consistent (although T*Z Pillia's trace P=0.174 for the multivariate test) and there was a significant depth effect (Appendix 3). Fig. 35 shows that there was no thermal stratification within zones 2 or 3 and that temperature was generally very similar within these zones on any one sampling occasion, the largest difference being 1 °C. Average surface temperature within zones 2 and 3 ranged from 10.6 to 20.0 °C. Within zone 1, observed differences in temperature between surface and bottom waters coincided with the presence of a halocline although the largest difference recorded was small, at approximately 2 °C. Average temperature at any depth within zone 1 ranged from 9.2 to 20.6 °C.

Table 16. Average values (n=6), yearly median and range (n= 30 or 36) for water quality parameters of surface waters, Earlham Lagoon (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	20.5 (10.5)	33.2 (1.0)	33.9 (0.6)	21.5 (8.5)	35.0 (0.5)	35.2 (0.9)	33.5	3.0	35.7
Temperature	°C	10.3 (0.9)	14.7 (1.0)	19.1 (0.4)	19.1 (0.9)	21.0 (0.6)	10.7 (0.3)	16.8	9.1	21.9
Dissolved O_2	mg l^{-1}	9.8 (0.6)	8.7 (0.3)		6.2 (0.5)	8.5 (0.3)	8.4 (0.9)	8.7	5.7	10.8
Turbidity	NTU	3.7 (0.7)	1.8 (0.6)	2.0 (0.5)	2.1 (1.1)	3.0 (1.1)	0.9 (0.2)	2.0	0.6	5.1
Chlorophyll *a*	µg l^{-1}	0.9 (0.6)	0.2 (0.2)	0.5 (0.4)	0.8 (0.8)	0.6 (0.6)	0.1 (0.2)	0.4	0.0	1.8
NO_x-N	µg l^{-1}	28 (3)	1 (2)	1 (1)	5 (3)	1 (1)	2 (1)	2	0	32
PO_4-P	µg l^{-1}	9 (1)	6 (1)	6 (2)	5 (2)	6 (1)	6 (2)	6	3	11
SiO_4-Si	µg l^{-1}	920 (210)	400 (150)	370 (100)	1140 (600)	410 (210)	190 (160)	475	30	2030
Total SS	mg l^{-1}	8.8 (1.3)	7.0 (3.1)	9.4 (4.5)	12.9 (8.0)	6.1 (0.7)	4.2 (1.8)	6.8	2.5	22.9
Volatile SS	mg l^{-1}	1.5 (0.3)	1.4 (0.6)	2.0 (1.6)	2.7 (1.3)	1.7 (0.2)	1.3 (0.2)	1.5	0.7	5.2
Fixed SS	mg l^{-1}	7.3 (1.0)	5.6 (2.5)	7.4 (4.6)	10.2 (6.7)	4.4 (0.6)	3.0 (1.7)	5.1	1.4	18.4

The patterns of DO within the zones and by depth were not consistent over time, although from Appendix 3 the evidence for depth was only weak (T*Z, P=0.203 for the uni-variate test). Figure Fig. 35 shows that, there was very little difference in DO by depth within zones 2 or 3 or between these zones. Average surface DO concentrations within these zones ranged from 5.8 to 9.4 mg/l and the largest difference between surface and bottom concentrations on any sampling occasion was less than 0.5 mg/l. Slightly greater variation was recorded within zone 1 where differences of up to 1 mg/l were observed which coincided with salinity and temperature stratification. Average DO at either depth within zone 1 ranged from 6.1 to 10.2 mg/l.

The first component of PCA described a positive relationship between the suspended solids and SiO_4-Si, but accounted for only 37 % of the variation in the data. The second component was solely from DO concentrations and accounted for 24 % of the variation in the data (Appendix 4).

Table 16 provides the average values of water quality parameters, for each sampling occasion, in surface waters within Earlham Lagoon. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

The largely unstratified nature of Earlham Lagoon indicates that surface waters are likely to be generally representative of conditions at depth within most of the estuary, the exception being within zone 1 when the salinity in surface waters is low. The level of the main water quality parameters was low on most sampling occasions, although PO_4-P concentrations were generally in the medium range suggesting some anthropogenic input may occur. The median value recorded for turbidity was 2.0 NTU while median chlorophyll, NO_x-N and PO_4-P concentrations were, 0.4, 2 and 6 µg l^{-1}, respectively. These levels suggest that Earlham Lagoon is a relatively healthy estuary.

3.1.16 Browns River

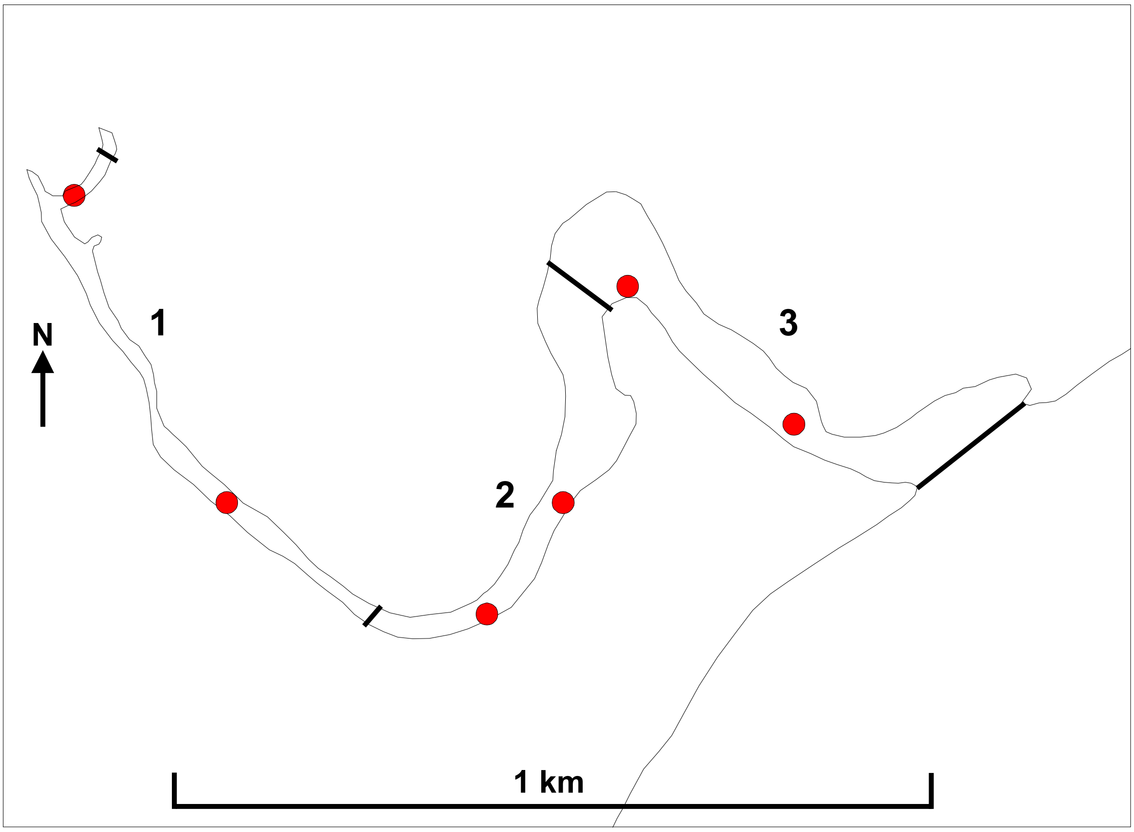

Fig. 36. Browns River showing fixed sampling sites and zones.

Browns River was classified as an open estuary by Edgar *et al.* (1999). The estuary was open on the first four sampling occasions but was closed by a sand barrier in March and May 2000. The estuary is relatively narrow and varies in depth from approximately 1 to 3 m at low tide. Edgar *et al.* (1999) identified the Browns River estuary as being of low conservation significance. The National Land and Water Resources Audit identified the Browns River estuary as being an extensively modified, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

The pattern of salinity over time within the zones was not consistent by depth (Appendix 3). Fig. 37 shows that the estuary was generally stratified within all zones. The exception to this was in March 2000 when salinity at all depths was approximately 33 ppt. The pattern of salinity was similar within zones 1 and 2 with bottom salinity ranging from 28.4 to 33.1 ppt and surface salinity from 0.9 to 32.9 ppt. The largest difference between surface and bottom salinity within these zones on any one sampling occasion was over 30 ppt. Zone 3 tended to be more mixed than the other zones with the largest difference recorded between surface and bottom salinity being less than 7 ppt. Within zone 3, surface salinity ranged from 3.1 to 32.9 ppt and bottom salinity from 4.7 to 32.9 ppt. Interestingly, during July 1999, bottom water was 27 ppt less saline at the mouth of the estuary than within zones 1 or 2.

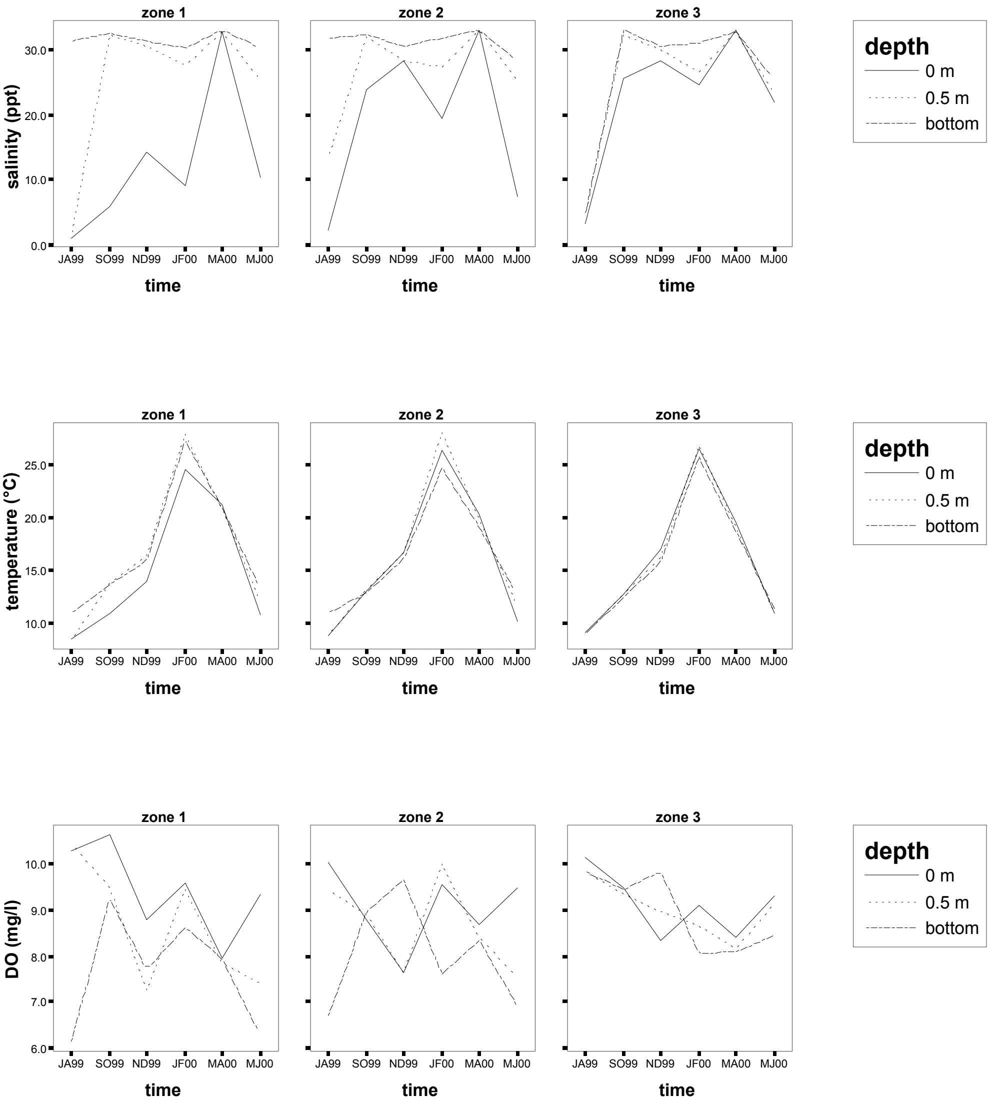

Fig. 37. Average salinity, temperature and DO, by zone and depth, Browns River (JA99 – MJ00)

There was some weak evidence that the pattern of temperature over time within the zones and depth was not consistent (although T*Z Pillia's trace P = 0.264 and T*D Pillia's trace P = 0.177 for the multivariate test). In addition, there was a significant interaction between zone and depth (Appendix 3). Fig. 37 shows that there was very little thermal stratification within zone 3 with the largest difference between the surface and bottom waters being just over 1 °C. Surface temperatures within this zone ranged from 9.0 to 26. 5 °C. Within the other zones, the difference between the surface and bottom was up to 3 °C. The average temperature recorded within these zones ranged from 8.3 to 28.0 °C. Interestingly, the temperature recorded at the 0.5 m depth was slightly higher than either the surface or bottom on some sampling occasions.

Table 17. Average values (n=6), yearly median and range (n= 36) for water quality parameters of surface waters, Browns River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	2.0 (1.2)	18.4 (11.2)	23.6 (10.0)	17.7 (8.5)	32.9 (0.1)	13.3 (7.6)	20.9	0.0	33.0
Temperature	°C	8.7 (0.3)	12.2 (1.3)	15.8 (1.7)	25.8 (1.6)	20.3 (1.0)	10.6 (0.4)	13.2	8.1	27.1
Dissolved O_2	mg l^{-1}	10.2 (0.3)	9.7 (1.1)	8.3 (0.8)	9.4 (0.5)	8.4 (0.5)	9.4 (0.4)	9.3	7.4	11.7
Turbidity	NTU	56.0 (2.1)	1.8 (0.5)	3.9 (2.1)	5.0 (3.8)	5.1 (2.6)	3.1 (2.0)	3.2	1.3	59.3
Chlorophyll *a*	µg l^{-1}	2.4 (0.2)	0.7 (0.6)	2.5 (1.2)	7.0 (2.7)	9.2 (4.4)	4.7 (6.3)	2.6	0.1	17.1
NO_x-N	µg l^{-1}	332 (43)	8 (4)	3 (2)	1 (2)	1 (0)	10 (2)	5	0	399
PO_4-P	µg l^{-1}	8 (1)	14 (3)	25 (6)	13 (11)	42 (16)	17 (5)	16	2	63
SiO_4-Si	µg l^{-1}	4460 (220)	340 (170)	670 (50)	740 (160)	20 (30)	1750 (270)	690	0	4830
Total SS	mg l^{-1}	41.2 (7.1)	5.4 (0.8)	17.0 (6.3)	10.5 (9.0)	7.8 (1.4)	6.5 (5.5)	8.5	2.9	53.1
Volatile SS	mg l^{-1}	7.5 (1.0)	1.2 (0.1)	3.9 (1.5)	3.3 (4.5)	3.4 (1.7)	2.5 (1.6)	2.7	0.0	9.4
Fixed SS	mg l^{-1}	33.6 (6.2)	4.2 (0.7)	13.1 (5.0)	7.2 (7.1)	4.4 (2.0)	4.0 (4.0)	5.9	1.2	43.7

The pattern of DO over time by depth was not consistent and there was a significant interaction between zone and depth (Appendix 3). There was less variability in DO within zone 3 than the other zones (Fig. 37). The largest difference recorded between surface and bottom waters was less than 1.5 mg/l with concentrations ranging from 8.1 to 10.2 mg/l. Within zones 1 and 2, the difference between surface and bottom levels was over 4 mg/l on some sampling occasions. Average DO within these zones ranged from 7.7 to 10.7 mg/l on the surface and 6.1 to 9.7 mg/l on the bottom.

The first component of PCA for the Browns River estuary accounted for 48 % of the variation in the data and described the parameters of turbidity, suspended solids (total and fixed) and NO_x-N being negatively related to salinity and temperature. The second component was derived solely from chlorophyll concentrations and accounted for 24 % of the variation in the data (Appendix 4). However, given the highly stratified nature of the estuary on most occasions, water quality in surface waters is unlikely to be representative of conditions greater than 0.5 m below the surface.

Table 17 provides the average values of water quality parameters, for each sampling occasion, in surface waters for Browns River. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Levels of the main water quality indicators were generally medium to very high. As seen from the PCA, elevated turbidity and NO_x-N were linked to increased freshwater input in the estuary. Very high mean turbidity (56 NTU) and NO_x-N concentrations (332 µg l^{-1}) were recorded in July 1999 when surface salinity averaged 2.0 ppt. Interestingly, NO_x-N concentrations were low on all other sampling occasions with the median level being 5 µg l^{-1}. Chlorophyll tended to be in the medium to high level ranging from 0.1 to 17.1 µg l^{-1} and PO_4-P levels were medium to high ranging from 2 to 63 µg l^{-1}. The elevated levels of the main water quality indicators in surface waters suggest that Browns River is a relatively unhealthy estuary and may be susceptible to eutrophication.

3.1.17 Cloudy Bay Lagoon

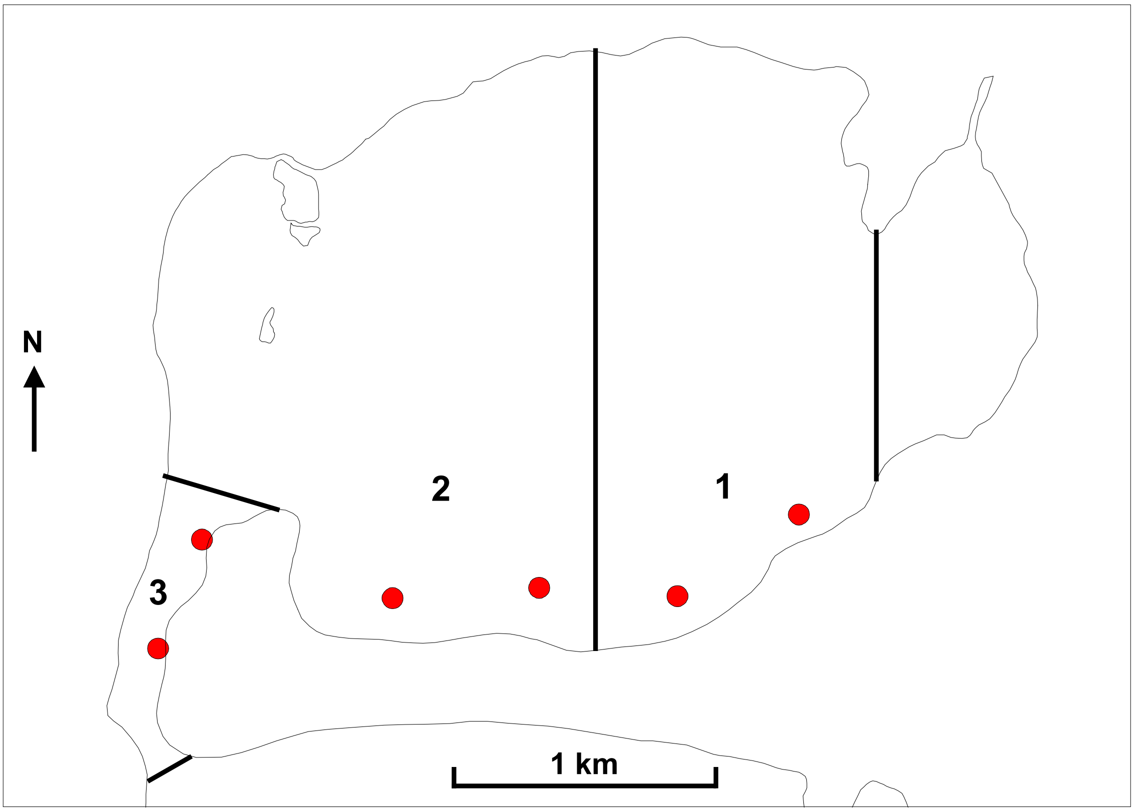

Fig. 38. Cloudy Bay Lagoon showing fixed sampling sites and zones.

Cloudy Bay Lagoon is a shallow marine inlet (Edgar *et al.* 1999). The main part of the estuary (zones 1 and 2) is approximately 1 m in depth at low tide, although there is a slightly deeper basin in the centre of the lagoon (not sampled in this study). At low tide, zone 3 consists of large sandflats and a relatively narrow channel that is approximately 2 to 3 m in depth. Edgar *et al.* (1999) identified Cloudy Bay Lagoon as being of high conservation significance. The National Land and Water Resources Audit identified Cloudy Bay Lagoon as being a near pristine, wave dominated estuary (subclass: wave estuary) (NLWRA 2002).

Fig. 39 shows that salinity was reasonably constant throughout the estuary with the average surface salinity within any zone over the sampling period ranging from 33. 3 to 35 .8 ppt. However, the pattern of salinity over time was not consistent within the zones (Appendix 3). Generally, salinity increased slightly from zone 1 to 3. However, this pattern was reversed in January 2000 when zone 1 approached hyper-salinity suggesting that the upper estuary (which was not sampled) was hyper-saline at this time.

The pattern of temperature over time was also inconsistent within the zones (Appendix 3). Fig. 39 shows that on the first 3 sampling occasions temperature was generally similar within zone 2 and 3 and zone 1 was slightly cooler. But during January 2000 the temperature was lower in zone 3 than the other zones. The average surface temperature recorded within the zones ranged from 8.6 to 22.6 °C with the maximum recorded difference between zones on any sampling occasion being less than 3 °C.

The pattern of DO over time was not consistent by depth and there was weak evidence that the pattern of DO over time was not consistent by zone (although T*Z Pillia's trace P = 0.140 for the multivariate test) (Appendix 3). However, Fig. 40 shows that there was very little difference by depth with the largest difference recorded between average surface and bottom concentrations within any one zone being only 0.3 mg/l. DO tended to be less variable within zone 2, average surface values ranging from 7.8 to 10.4 mg/l. Average surface values within zones 1 and 3 ranged from 7.7 to 12.8 mg/l. The largest difference recorded between zones on any one sampling occasion was 3.5 mg/l.

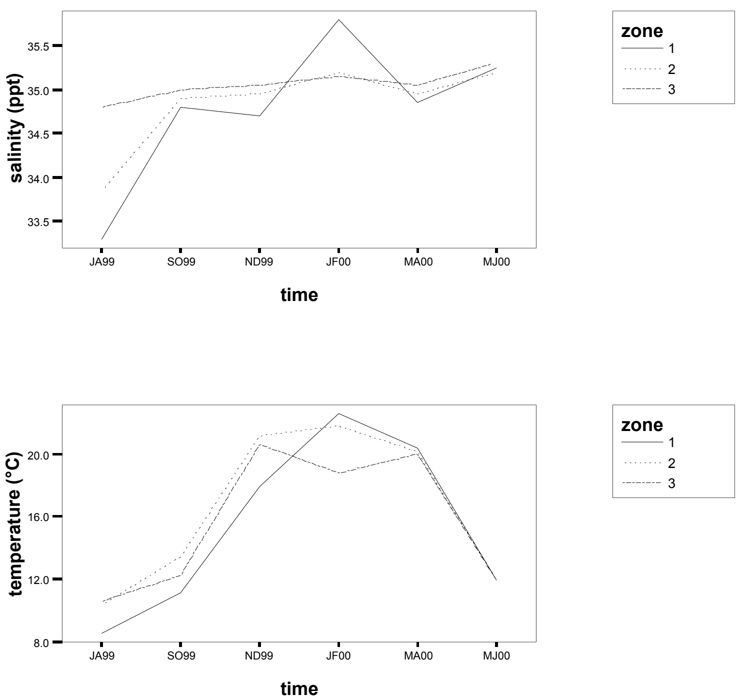

Fig. 39. Average surface salinity and temperature, by zone, Cloudy Bay (JA99 – MJ00)

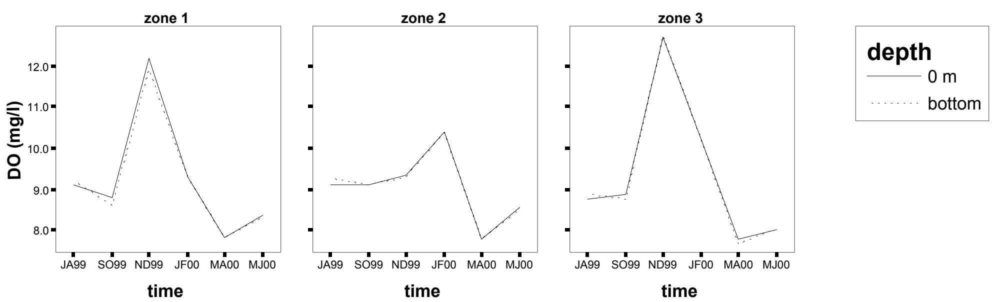

Fig. 40. Average DO, by zone and depth, Cloudy Bay (JA99 –MJ00)

Table 18. Average values (n=6), yearly median and range (n= 36) for water quality parameters of surface waters, Cloudy Bay Lagoon (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	Units	JA 99	SO 99	ND 99	JF 00	MA 00	MJ 00	99 / 00	Min	Max
Salinity	ppt	34.0 (0.7)	34.9 (0.1)	34.9 (0.2)	35.4 (0.3)	35.0 (0.1)	35.3 (0.1)	35.0	33.2	35.9
Temperature	°C	9.8 (1.0)	12.2 (1.1)	19.9 (1.8)	21.1 (1.8)	20.2 (0.4)	11.9 (0.1)	16.0	8.3	22.6
Dissolved O_2	mg l^{-1}	9.0 (0.3)	8.9 (0.2)	11.4 (2.3)	10.0 (0.9)	7.8 (0.2)	8.3 (0.3)	8.8	7.6	14.3
Turbidity	NTU	1.2 (0.5)	0.9 (0.2)	1.4 (0.7)	1.1 (0.3)	1.0 (0.4)	1.4 (0.8)	1.0	0.6	2.8
Chlorophyll *a*	µg l^{-1}	2.5 (1.0)	0.9 (1.0)	0.3 (0.3)	0.9 (1.2)	0.6 (0.6)	1.0 (0.5)	0.7	0.0	3.7
NO_x-N	µg l^{-1}	7 (11)	4 (3)	0 (1)	2 (2)	1 (1)	13 (4)	1	0	25
PO_4-P	µg l^{-1}	6 (3)	4 (2)	5 (1)	9 (4)	5 (2)	9 (2)	6	2	16
SiO_4-Si	µg l^{-1}	50 (40)	20 (20)	20 (10)	60 (40)	60 (30)	40 (10)	40	10	130
Total SS	mg l^{-1}	6.6 (3.4)	5.6 (5.6)	8.8 (3.4)	5.8 (1.8)	9.4 (5.6)	12.7 (6.1)	7.2	2.4	23.1
Volatile SS	mg l^{-1}	1.6 (0.5)	1.4 (0.6)	2.3 (0.9)	1.9 (0.5)	1.5 (0.6)	1.9 (0.5)	1.8	0.7	3.7
Fixed SS	mg l^{-1}	4.9 (3.0)	4.2 (2.3)	6.6 (2.7)	3.9 (1.4)	7.9 (5.1)	10.7 (5.7)	5.2	1.4	20.6

PCA showed few strong relationships between the water quality parameters with the first component, the suspended solids, accounting for only 29 % of the variation in the data. The second component described a negative relationship between chlorophyll and temperature and accounted for 20 % of the variation (Appendix 4).

Table 18 provides the average values of water quality parameters, for each sampling occasion, in surface waters within Cloudy Bay Lagoon. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Cloudy Bay Lagoon was unstratified for all of the study and water quality parameters measure from the surface should therefore be representative of conditions throughout the estuary. The level of the main water quality parameters were generally low on most sampling occasions, although PO_4-P concentrations were within the medium range were experienced on some occasions. The median value recorded for turbidity was 1.0 NTU while median chlorophyll, NO_x-N and PO_4-P concentrations were, 0.7, 1 and 6 µg l^{-1}, respectively. These levels suggest that Cloudy Bay Lagoon is a relatively healthy estuary.

3.1.18 Catamaran River

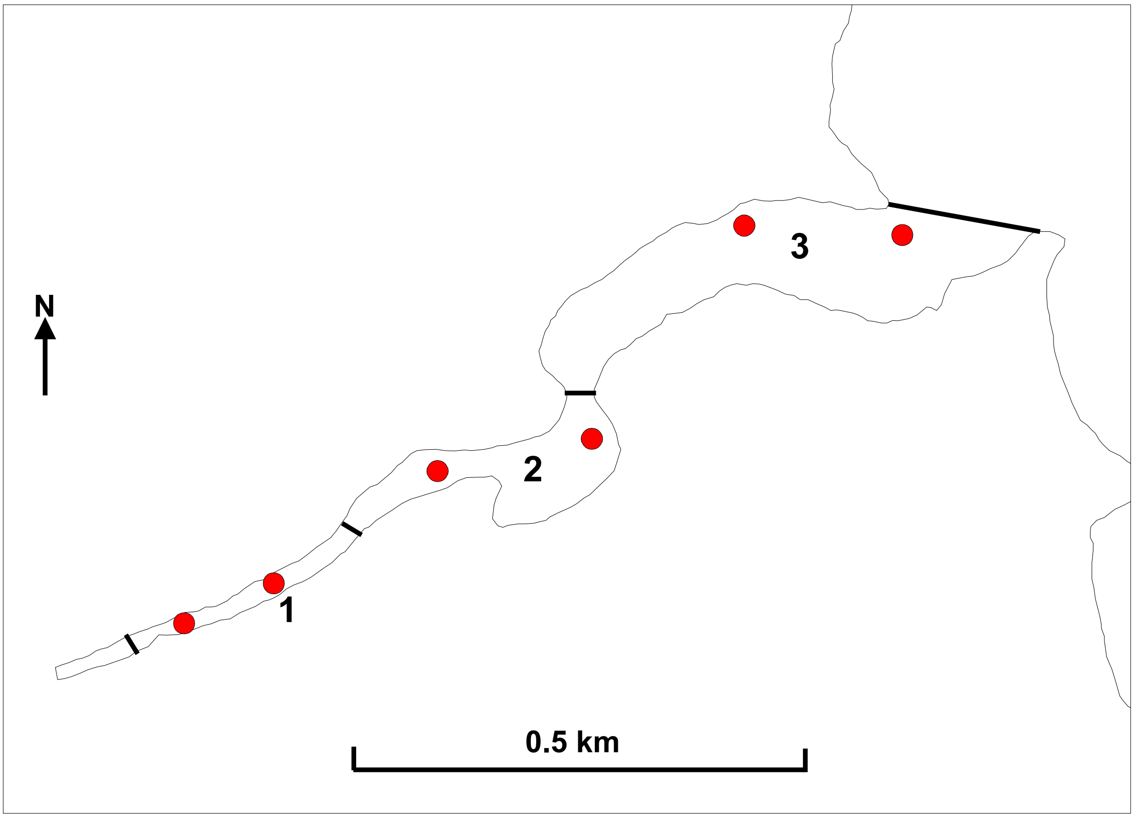

Fig. 41. Catamaran River showing fixed sampling sites and zones.

The Catamaran River is classified as an open estuary (Edgar *et al.* 1999). The estuary has a rocky bottom and shoreline and at low tide is approximately 2 to 3 m in depth within zone 3, and, 1 to 2 m in zones 1 and 2. Edgar *et al.* (1999) identified the Catamaran River estuary as being of high conservation significance. The National Land and Water Resources Audit identified the Catamaran River estuary as being a near pristine, wave dominated estuary (NLWRA 2002).

The patterns of salinity, temperature and DO over time within the zones were not consistent by depth although for each of these parameters the multivariate test was not significant (T*Z*D Pillia's trace P= 0.116, P= 0.350 and P = 0.265, respectively) (Appendix 3). Generally, the surface waters were relatively fresh and increased in salinity from zone 1 to zone 3 (Fig. 42). In zone 1, average surface salinity ranged from 0.0 to 9.9 ppt and from 3.6 to 23.5 ppt in zone 3. A halocline existed at approximately 0.5 to 1 m in depth in all zones on all sampling occasions. The average bottom salinity within zone 1 was highly variable ranging from 9.7 to 33.3 ppt. The bottom salinity within zones 2 and 3 was less variable and showed a similar pattern, average values ranging from 29.0 to 34. 2 ppt in zone 1 and 33.8 to 35.0 ppt in zone 3.

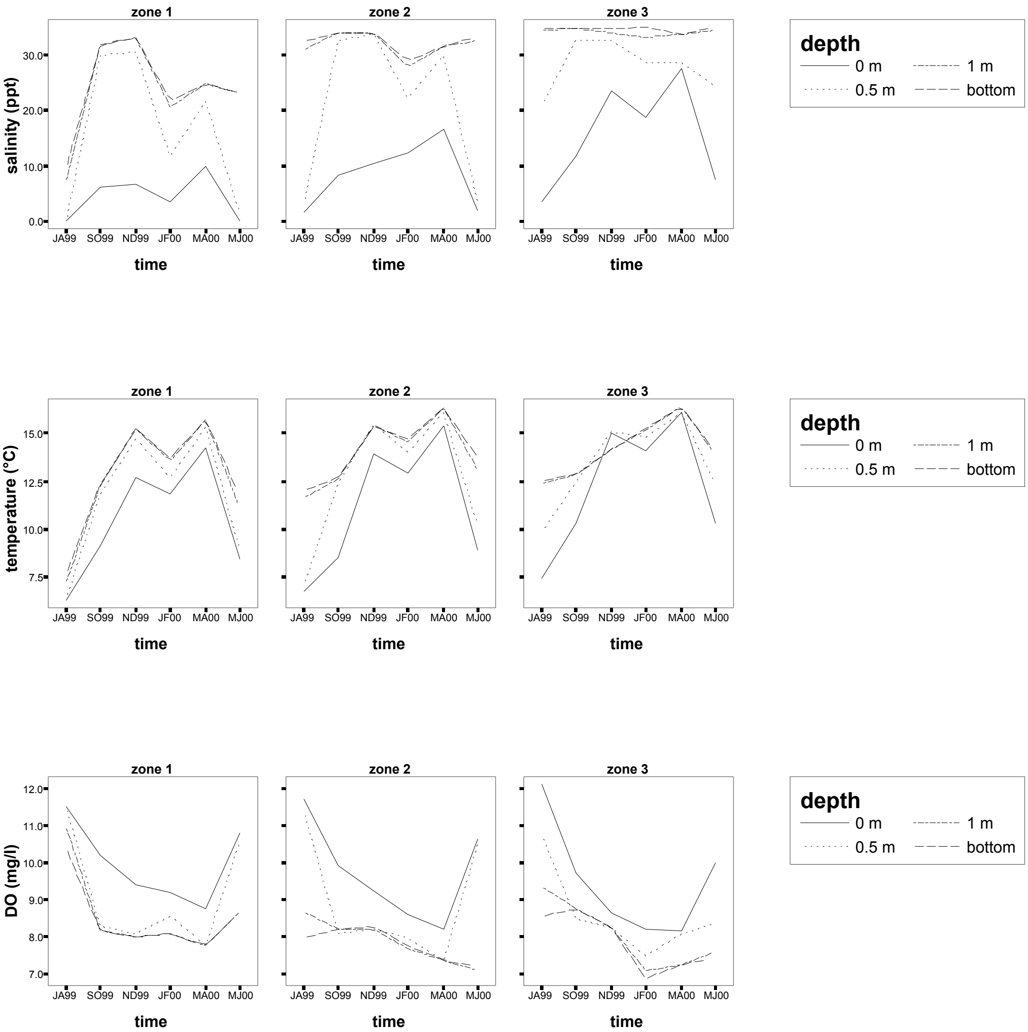

Fig. 42. Average salinity, temperature and DO, by zone and depth, Catamaran River (JA99 – MJ00)

Within all zones, the temperature tended to be lower on the surface than at the bottom except for the November 1999 when the surface by about 1 °C warmer (Fig. 42). The average temperature within any of the zones ranged from 6.3 to 16.2 °C on the surface and 7.7 to 16.5 °C on the bottom. The difference in temperature between the surface and bottom was generally at least 1 to 2 degrees cooler with the maximum difference recorded in July 1999 of over 5 °C.

As for salinity and temperature, there was a generally a distinct difference in DO concentration by depth within all zones. Average DO levels were highest in the surface waters on all sampling occasions and ranged from 8.2 to 12.1 mg/l between the zones. Bottom salinity within the zones ranged from 6.9 to 10.4 mg/l. The largest difference recorded between surface and bottom waters in any zone on a sampling occasion was almost 4 mg/l.

Table 19. Average values (n=6), yearly median and range (n= 36) for water quality parameters of surface waters, Catamaran River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	1.7 (1.6)	8.8 (2.7)	13.5 (8.3)	11.5 (7.4)	18.0 (8.6)	3.1 (3.9)	7.9	0.0	31.4
Temperature	°C	6.8 (0.5)	9.4 (0.9)	13.9 (1.1)	13.0 (1.1)	15.3 (0.9)	9.2 (0.9)	11.1	6.3	16.3
Dissolved O_2	mg l^{-1}	11.8 (0.4)	9.9 (0.2)	9.1 (0.4)	8.7 (0.5)	8.4 (0.5)	10.5 (0.5)	9.6	7.7	12.6
Turbidity	NTU	3.1 (0.3)	1.2 (0.3)	1.2 (0.5)	2.0 (0.6)	1.1 (0.2)	2.0 (0.4)	1.5	0.8	3.4
Chlorophyll *a*	µg l^{-1}	0.0 (0.0)	0.6 (0.6)	0.5 (0.4)	0.1 (0.1)	0.1 (0.2)	0.0 (0.1)	0.0	0.0	1.2
NO_x-N	µg l^{-1}	13 (11)	9 (1)	0 (1)	1 (0)	6 (2)	9 (10)	5	0	29
PO_4-P	µg l^{-1}	4 (3)	7 (1)	5 (2)	5 (2)	5 (2)	4 (4)	5	1	11
SiO_4-Si	µg l^{-1}	270 (170)	260 (90)	210 (130)	440 (100)	450 (210)	280 (160)	340	40	830
Total SS	mg l^{-1}	3.2 (1.7)	4.0 (1.2)	4.6 (1.2)	3.7 (0.9)	2.8 (1.0)	2.8 (0.7)	3.4	0.9	5.7
Volatile SS	mg l^{-1}	1.2 (0.6)	1.4 (0.3)	1.7 (0.4)	1.1 (0.1)	0.7 (0.2)	1.3 (0.2)	1.2	0.6	2.0
Fixed SS	mg l^{-1}	1.9 (1.2)	2.5 (1.0)	3.0 (1.0)	2.6 (0.8)	2.1 (0.8)	1.5 (0.5)	2.1	0.2	4.1

The first component of PCA accounted for 44 % of the variation in the data and described a salinity, temperature, PO_4-P and suspended solids (total and fixed) having a negative relationship with turbidity and DO. The second component was derived solely from volatile SS concentrations and accounted for 20 % of the variation in the data (Appendix 4). However, given the highly stratified nature of the estuary, water quality in surface waters is unlikely to be representative of conditions greater than 0.5 m below the surface on most occasions.

Table 19 provides the average values of water quality parameters, for each sampling occasion, in surface waters for Browns River. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Levels of the main water quality indicators were generally low. The median value recorded for turbidity was 1.5 NTU while median chlorophyll, NO_x-N and PO_4-P concentrations were, 0.0, 5 and 5 µg l^{-1}, respectively, indicating that the Catamaran River estuary is a relatively healthy estuary.

3.1.19 Cockle Creek

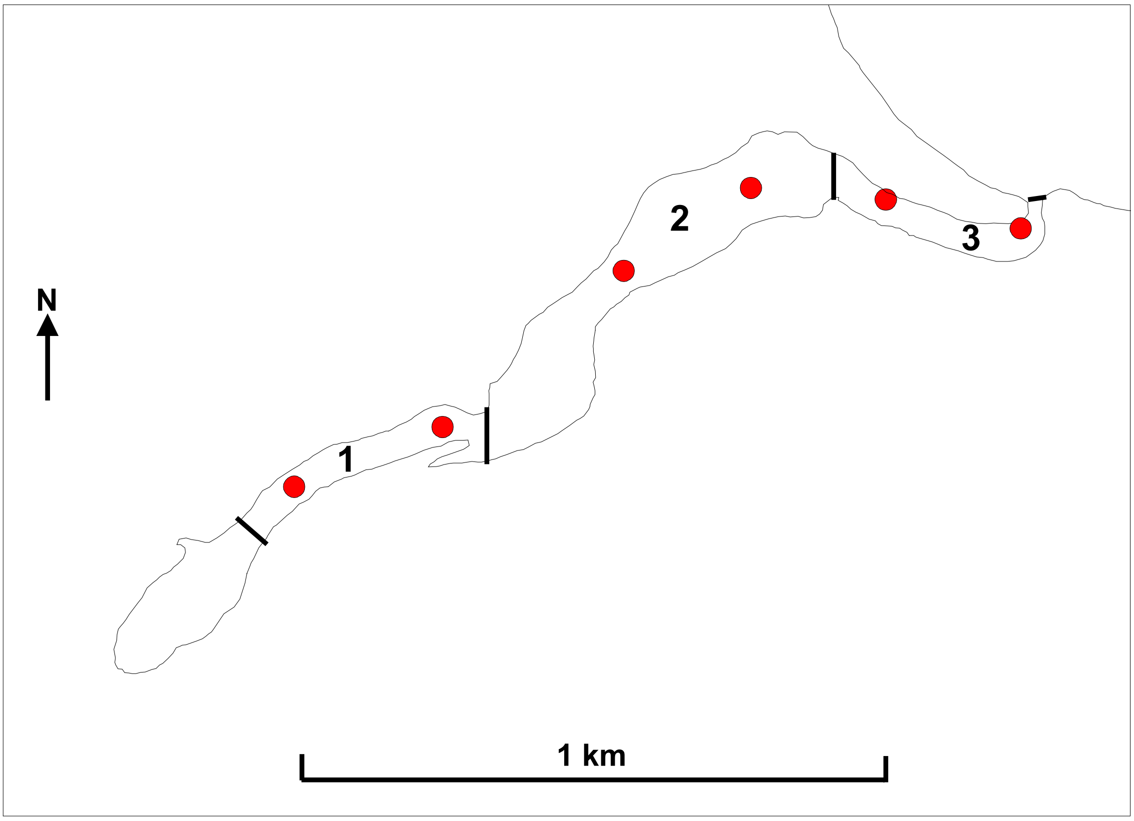

Fig. 43. Cockle Creek showing fixed sampling sites and zones.

Cockle Creek is as an open estuary (Edgar *et al.* 1999). At low tide, the estuary consists of a relatively narrow channel less than 1 m in depth and exposed sandlflats. Edgar *et al.* 1999 identified the Cockle Creek estuary as being of moderate conservation significance. The National Land and Water Resources Audit identified the Cockle Creek estuary as being a near pristine, wave dominated estuary (NLWRA 2002).

There was weak evidence that the pattern of salinity over time in the zones was not consistent by depth (although T*Z*D Pillia's trace P = 0.558 for the multivariate test) (Appendix 3). Fig. 44 shows that, in general, the estuary was well mixed. However, increased freshwater in the head of the estuary resulted in stratification within zones 2 and 3 during June 1999 and within zone 1 during May 2000 (and slight stratification in zones 2 and 3). The largest variation in salinity occurred within zones 1 and 2, average surface salinity ranging from 0.2 to 35.1 ppt. The greatest difference in salinity between the surface and bottom within these zones was 22 ppt in July 1999. Surface salinity within zone 3 ranged from 21.0 to 35.1 ppt, the greatest difference from the bottom being 11 ppt.

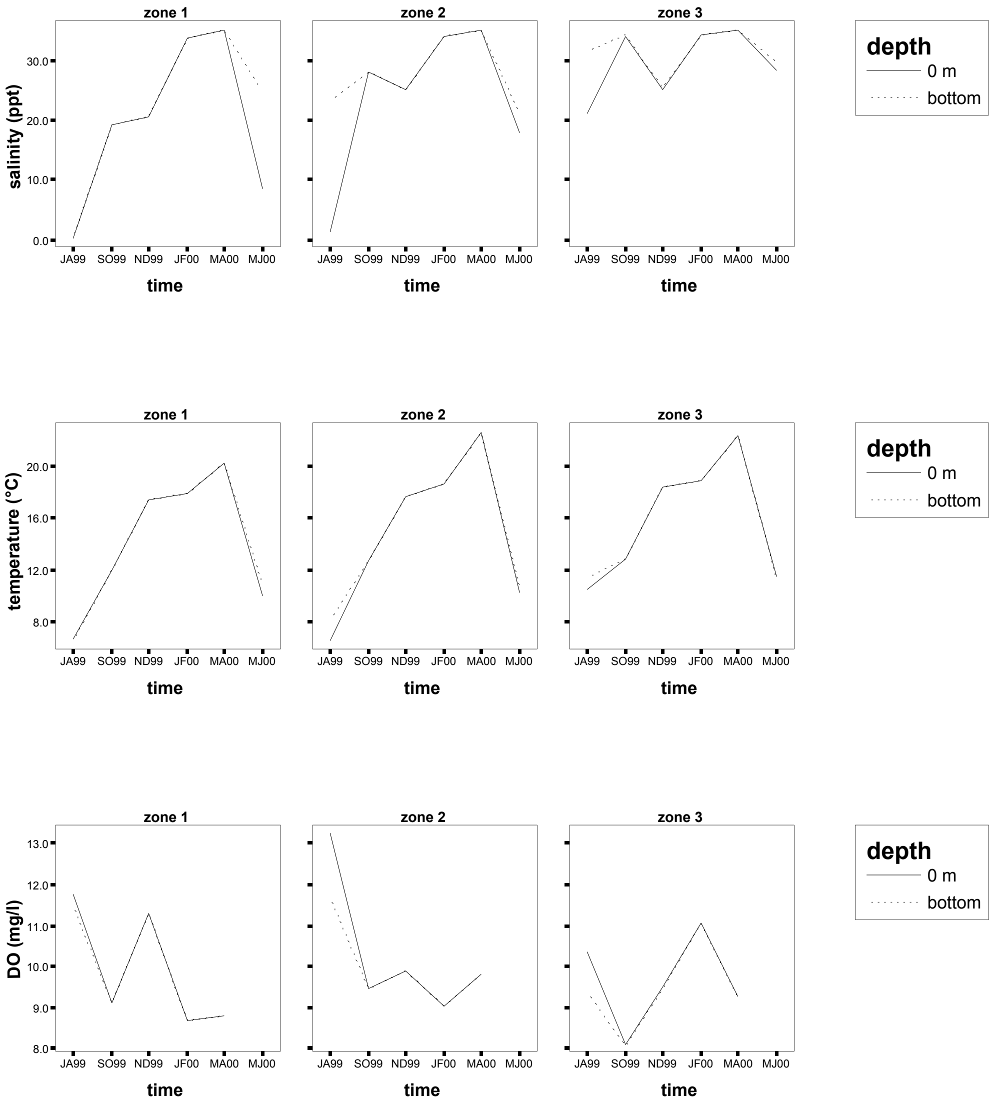

Fig. 44. Average salinity, temperature and DO, by zone and depth, Cockle Creek (JA99 – MJ00)

The pattern of temperature over time by zone and depth was not consistent although the evidence for depth was only weak (T*D Pillia's trace P = 0.561 for the multivariate test) (Appendix 3). Fig. 44 shows that on most sampling occasions there was no thermal stratification, the exception being a slight difference (< 1.5 °C) in zones 2 and 3 in July 1999, when these parts of the estuary also showed salinity stratification. The average surface temperature within zones 1 and 2 ranged from 6.5 to 22.7 °C and from 10.5 to 22.4 °C in zone 3.

Table 20. Average values (n=6), yearly median and range (n= 30 or 36) for water quality parameters of surface waters, Cockle Creek (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	7.5 (11.8)	27.1 (7.3)	23.6 (2.7)	33.8 (0.3)	35.1 (0.1)	18.2 (9.6)	25.3	0.1	35.1
Temperature	°C	7.9 (2.1)	12.5 (0.4)	17.8 (0.5)	18.5 (0.5)	21.8 (1.2)	10.6 (0.8)	15.0	6.3	22.7
Dissolved O_2	mg l^{-1}	11.8 (1.4)	8.9 (0.8)	10.2 (0.9)	9.6 (1.1)	9.3 (0.6)		9.5	8.0	13.6
Turbidity	NTU	3.5 (1.7)	1.0 (0.6)	1.3 (0.4)	1.3 (0.3)	1.6 (0.6)	1.5 (0.3)	1.4	0.4	4.8
Chlorophyll *a*	µg l^{-1}	0.7 (0.4)	1.2 (1.9)	0.6 (0.2)	0.1 (0.1)	1.1 (1.1)	0.8 (0.8)	0.4	0.0	3.8
NO_x-N	µg l^{-1}	22 (12)	5 (5)	1 (0)	1 (1)	1 (2)	7 (9)	2	0	34
PO_4-P	µg l^{-1}	5 (3)	7 (3)	2 (0)	4 (2)	3 (1)	3 (3)	4	1	10
SiO_4-Si	µg l^{-1}	530 (310)	360 (370)	360 (160)	190 (170)	80 (80)	670 (190)	280	40	940
Total SS	mg l^{-1}	8.8 (6.4)	4.5 (1.1)	5.6 (1.9)	9.7 (4.1)	10.6 (4.0)	5.6 (1.0)	6.3	2.0	17.6
Volatile SS	mg l^{-1}	2.0 (1.0)	1.5 (0.5)	1.3 (0.4)	2.7 (0.9)	1.6 (0.4)	2.2 (0.5)	1.9	0.7	4.5
Fixed SS	mg l^{-1}	6.8 (5.4)	3.0 (1.0)	4.3 (1.5)	7.0 (3.2)	9.0 (4.1)	3.5 (0.8)	4.5	1.1	14.6

There was also weak evidence that the pattern of DO over time in the zones was not consistent by depth (although T*Z*D Pillia's trace P = 0.233 for the multivariate test) (Appendix 3). As with salinity and temperature, there was generally no difference between DO by depth, except for when a halocline existed and a difference of less than 1.5 mg/l was recorded. Average surface DO levels within the zones ranged from 8.1 to 13.3 mg/l and the largest difference in DO between zones on any one sampling occasion was 4 mg/l.

The first component of PCA described salinity and temperature having a negative relationship with SiO_4-Si and accounted for 40 % of the variation in the data. The second component, accounting for 22 % of the variation, described the positive relationship between the suspended solids (Appendix 4).

Table 20 provides the average values of water quality parameters, for each sampling occasion, in surface waters within Cockle Creek. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

The largely unstratified nature of Cockle Creek indicates that surface waters are likely to be generally representative of conditions at all depths within the estuary. Levels of the main water quality indicators were generally low. The median value recorded for turbidity was 1.4 NTU while median chlorophyll, NO_x-N and PO_4-P concentrations were, 0.4, 2 and 4 µg l^{-1}, respectively, indicating that Cockle Creek is a relatively healthy estuary.

3.1.20 Pieman River

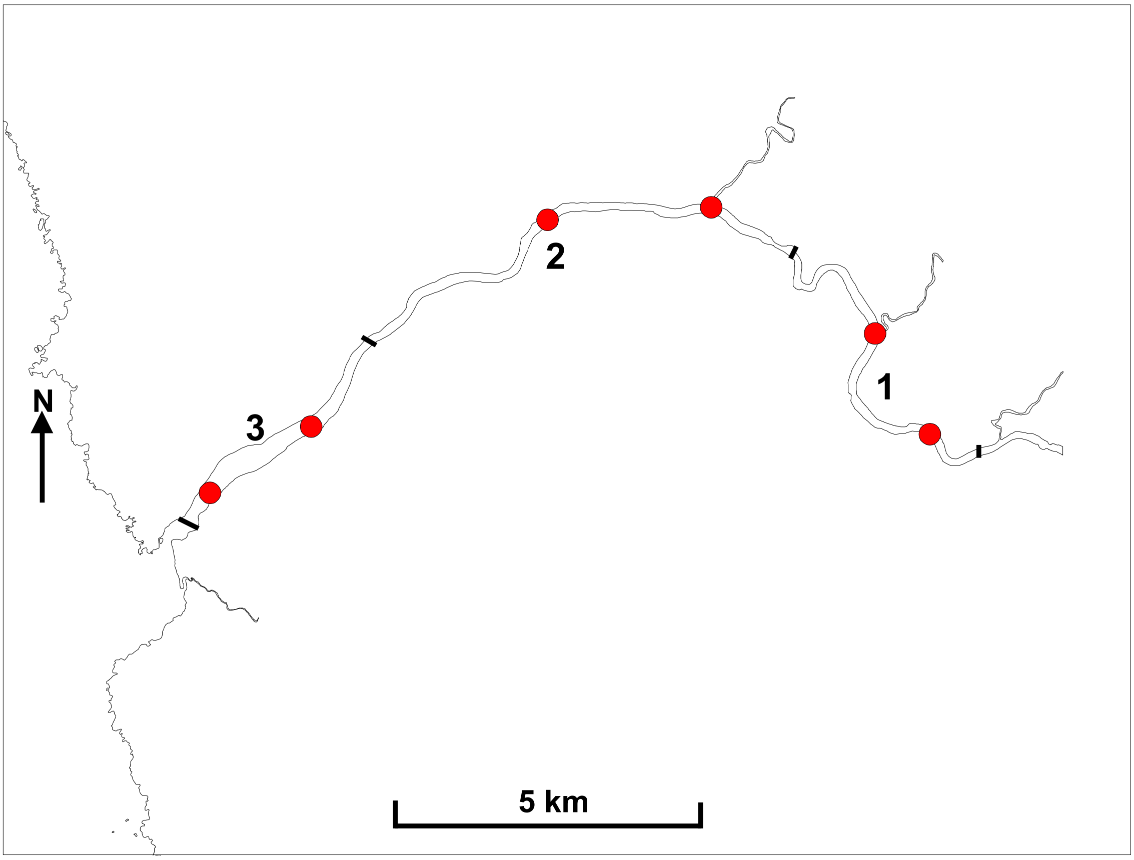

Fig. 45. Pieman River showing fixed sampling sites and zones.

The Pieman River is a large open microtidal river (Edgar *et al.* 1999). The estuary is relatively deep, being approximately 10 m in depth within most of the study region. Within zones 1 and 2, the river banks are heavily vegetated by forest which becomes more open as the river approaches the mouth. The estuary was open on all sampling occasions, although an extensive sand barrier was present during April 2000 and appeared to severely limit flow into and out of estuary (a similar barrier occurred at the Arthur River at the same time). Edgar *et al.* (1999) identified the Pieman River estuary as being of moderate conservation significance. The National Land and Water Resources Audit identified the Pieman River estuary as being a largely unmodified, tide(?) dominated estuary (NLWRA 2002).

The pattern of salinity by depth was not consistent over time and there was weak evidence that these patterns were not consistent within the zones (although T*Z*D P = 0.291 for the univariate test). Fig. 46 shows that the estuary was totally fresh at all depths during August 1999 and June 2000 (winter). On all other sampling occasions the estuary was vertically stratified in all zones. The depth of the halocline ranged from approximately 3 to 8 m between sampling events. On any one sampling occasion there was little difference in average salinity between zones within the top 2 m, the largest difference recorded being just over 2ppt in zone 1 during April 2000. The maximum average salinity was 1.9, 2.8 and 4.0 ppt at the surface and 33.8, 34.9 and 34.9 ppt at the bottom in zones 1, 2 and 3, respectively. On any one sampling occasion, the pattern of salinity by depth between zones was generally similar. Salinity values for depths other than the surface are not shown for February 2000 (missing data).

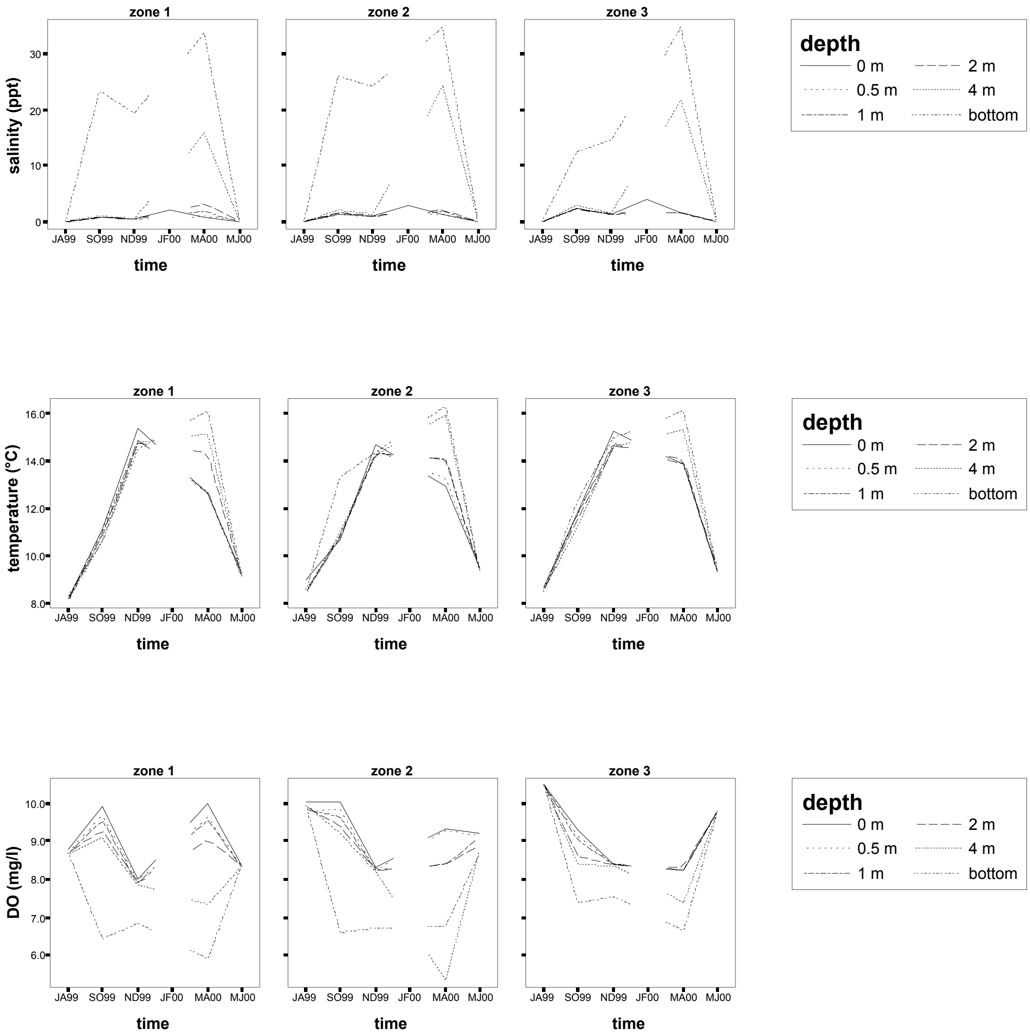

Fig. 46. Average salinity, temperature and DO, by zone and depth, Pieman River (JA99 – MJ00)

As for salinity, the pattern of temperature by depth was not consistent over time and there was weak evidence that these patterns were not consistent within the zones, although T*Z*D Pillia's trace, P = 0.258 for the univariate test (Appendix 3). Fig. 46 shows that the difference in temperature between zones and depth was generally less than 1.5 °C on any one sampling occasion. However, in April 2000 the difference in average temperature between the surface and bottom was up to 3.5 °C in each zone (and 2.5 °C within zone 2 in October 1999). It is also likely that a relatively large difference in temperature by depth occurred in February 2000 (missing data). Average temperature in any zone ranged from 8.2 to 15.4 °C on the surface and 8.4 to 16.3 °C on the bottom.

The pattern of DO over time was inconsistent by both zone and depth (Appendix 3). When there was no halocline (*ie.* winter), DO levels between the surface and bottom within any one zone were within 0.5 mg/l (Fig. 46). However, differences of over 4 mg/l were recorded within some zones on other sampling occasions. Average DO in any zone ranged from 8.0 to 10.5 mg/l on the surface and 5.9 to 10.5 mg/l on the bottom.

The first component of PCA accounted for 40 % of the variation in the data and described a positive correlation between turbidity and suspended solids (Appendix 4). Temperature comprised the second component and accounted for 27 % of the variation.

Table 21 provides average values of water quality parameters, for each sampling occasion, in surface waters within the Pieman River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given. Given the stratified nature of the estuary, water quality in surface waters will be unrepresentative of conditions at depths greater than 4 m, except during winter when the estuary consisted entirely of freshwater. Future monitoring of water quality in this estuary should include characterisation of turbidity and nutrients in bottom water.

The level of the main water quality parameters were low, or, low to medium on all sampling occasions. The median value recorded for turbidity was 2.6 NTU while median chlorophyll, NO_x-N and PO_4-P concentrations were, 0.0, 23 and 0 $\mu g\ l^{-1}$, respectively. PO_4-P concentrations were exceptionally low. These values suggest that, from a water quality perspective of surface waters, the Pieman River estuary is a comparatively healthy estuary. However, NO_x-N values were within the medium range on most sampling occasions although this is most likely associated with the predominantly freshwater nature of surface waters within the estuary. In addition (as was seen for the Arthur River estuary) it is likely that significantly reduced DO concentrations could occur in bottom water within in the upper reaches of the estuary during periods of low flow.

Table 21. Average values (n=6), yearly median and range (n= 30 or 36) for water quality parameters of surface waters, Pieman River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	Units	JA 99	SO 99	ND 99	JF 00	MA 00	MJ 00	99 / 00	Min	Max
Salinity	ppt	0.0 (0.0)	1.5 (0.9)	0.9 (0.4)	2.9 (1.0)	1.1 (0.7)	0.0 (0.0)	0.3	0.0	2.5
Temperature	°C	8.6 (0.4)	11.3 (0.6)	15.1 (0.4)		13.1 (0.9)	9.4 (0.1)	11.3	8.1	15.6
Dissolved O_2	$mg\ l^{-1}$	9.8 (0.8)	9.8 (0.4)	8.2 (0.5)		9.2 (1.0)	9.1 (0.7)	9.2	7.5	10.7
Turbidity	NTU	2.9 (0.3)	9.8 (3.7)	1.8 (0.2)	1.6 (0.1)	4.6 (3.9)	2.6 (0.2)	2.6	1.5	16.0
Chlorophyll *a*	$\mu g\ l^{-1}$	0.0 (0.0)	0.0 (0.0)	0.0 (0.1)	0.1 (0.2)	0.2 (0.5)	0.0 (0.0)	0.0	0.0	1.1
NO_x-N	$\mu g\ l^{-1}$	28 (1)	22 (2)	36 (1)	20 (5)	21 (5)	19 (3)	23	13	37
PO_4-P	$\mu g\ l^{-1}$	1 (0)	0 (1)	0 (0)	2 (2)	0 (0)	0 (0)	0	0	7
SiO_4-Si	$\mu g\ l^{-1}$	60 (10)	170 (40)	150 (20)	560 (110)	730 (230)	100 (20)	150	40	910
Total SS	$mg\ l^{-1}$	1.7 (0.8)	12.5 (2.6)	1.3 (0.7)	1.6 (1.8)	3.9 (2.2)	2.3 (0.3)	2.4	0.8	16.7
Volatile SS	$mg\ l^{-1}$	1.5 (0.1)	3.7 (0.8)	1.1 (0.2)	1.5 (0.1)	2.0 (0.6)	1.5 (0.1)	1.5	0.8	5.0
Fixed SS	$mg\ l^{-1}$	0.2 (0.8)	8.8 (2.2)	0.2 (0.7)	0.1 (1.8)	2.0 (1.6)	0.9 (0.3)	0.9	0.0	11.7

3.1.21 Nelson Bay River

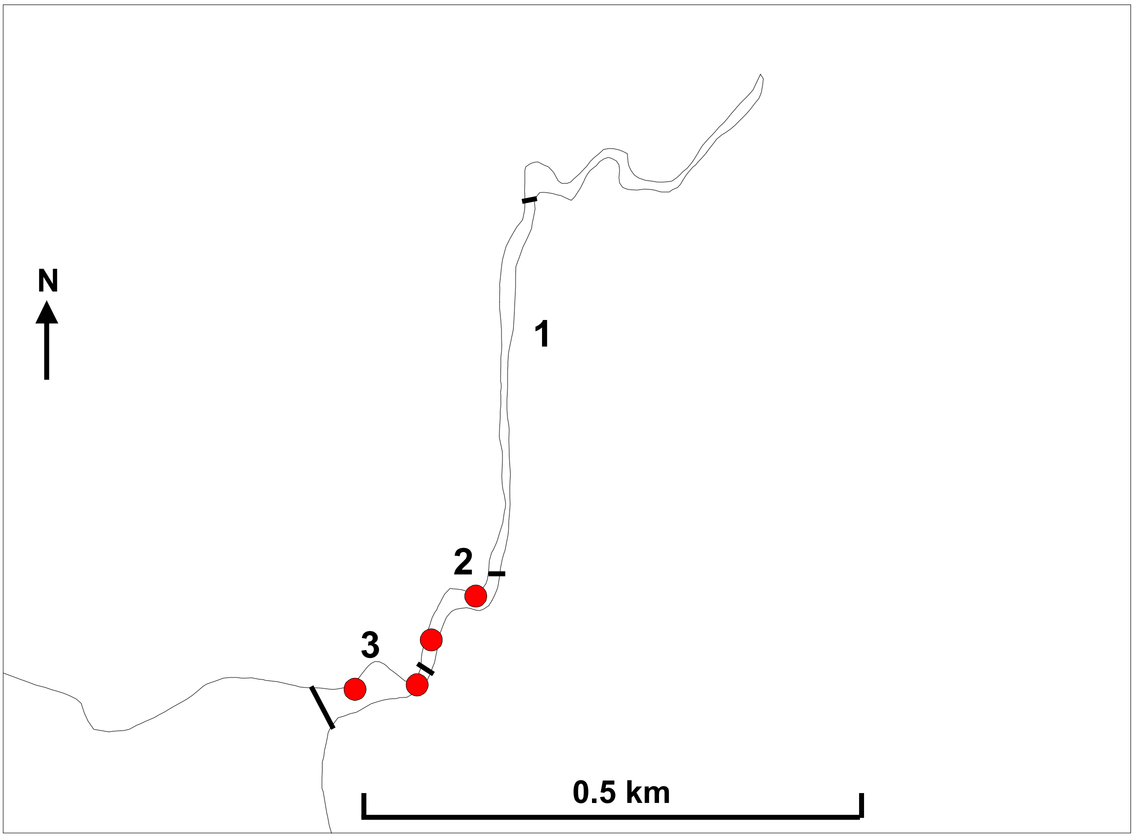

Fig. 47. Nelson Bay River showing fixed sampling sites and zones.

Nelson Bay River is as a barred, low-salinity estuary (Edgar *et al.* 1999). The mouth was closed during sampling in February and April 2000. The estuary is approximately 1 m in depth at low tide. Most of zone 3 has a sandy shore while the shore in zone 2 consists of vegetated banks. Zone 1 was not sampled due to difficulty in accessing the vegetated shoreline.

Edgar *et al.* (1999) identified the Nelson Bay River estuary as being of high conservation significance. The National Land and Water Resources Audit identified the Nelson Bay River estuary as being a near pristine, wave dominated estuary (NLWRA 2002).

There was weak evidence of an interaction between time and zone for salinity (although P = 0.245 for the univariate test) but there was no depth effect (Appendix 3). Fig. 48 shows that for the first three sampling occasions the estuary was totally fresh. When the estuary was closed, during summer, salinity had increased to an average of 7.6 ppt in zone 2 and between 9.6 and 11.2 ppt in zone 3. In June 2000, all samples were 0.0 ppt, except for the sample closest to the mouth which was 7.3 ppt.

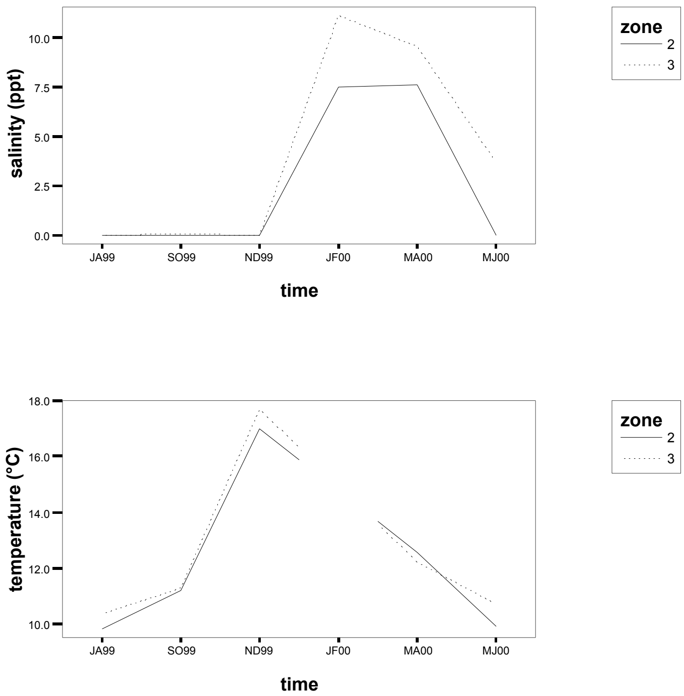

Fig. 48. Average surface salinity and temperature, by zone, Nelson Bay River (JA99 – MJ00)

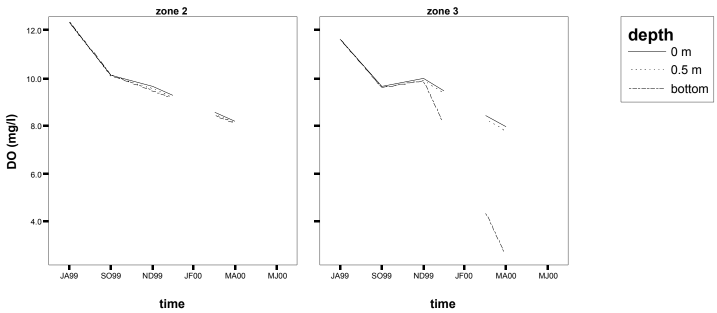

Fig. 49. Average DO, by zone and depth, Nelson Bay River (JA99 – MJ00)

There was a significant temperature effect by zone (Appendix 3) but the difference between zones was less than 1.0 °C on any one sampling occasion. Average temperature in any zone ranged from 9.9 to 17.0 °C, although temperatures in February 2000 (missing data) are likely to have been higher than this maximum.

Table 22. Average values (n=4), yearly median and range (n= 16, 20 or 24) for water quality parameters of surface waters, Nelson Bay River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	0.0 (0.0)	0.0 (0.1)	0.0 (0.0)	9.3 (2.2)	8.6 (1.4)	1.8 (3.7)	0.0	0.0	10.4
Temperature	°C	10.1 (0.4)	11.3 (0.1)	17.4 (0.6)		12.4 (0.4)	10.3 (0.7)	11.3	9.8	18.2
Dissolved O_2	mg l^{-1}	12.0 (0.5)	9.9 (0.4)	9.8 (0.3)		8.1 (0.2)		9.9	7.9	12.6
Turbidity	NTU	6.2 (0.4)	10.7 (0.7)	5.9 (1.1)	4.2 (1.8)	1.3 (0.3)	3.1 (0.2)	5.2	1.0	11.4
Chlorophyll *a*	µg l^{-1}	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)	3.4 (0.9)	1.5 (0.6)	0.0 (0.0)	0.0	0.0	4.5
NO_x-N	µg l^{-1}	13 (1)	7 (1)	8 (1)	2 (1)	3 (1)	8 (3)	7	1	13
PO_4-P	µg l^{-1}	2 (0)	1 (1)	1 (0)	8 (3)	5 (4)	2 (1)	2	0	11
SiO_4-Si	µg l^{-1}	20 (0)	50 (10)	20 (0)	280 (90)	540 (100)	100 (120)	40	20	660
Total SS	mg l^{-1}	5.9 (0.6)	8.5 (4.2)	3.5 (2.2)	9.0 (2.6)	3.3 (0.6)	5.7 (3.0)	5.5	1.3	14.4
Volatile SS	mg l^{-1}	2.8 (0.2)	4.5 (0.6)	2.6 (0.6)	3.2 (0.6)	1.4 (0.1)	1.6 (0.4)	2.6	1.3	5.2
Fixed SS	mg l^{-1}	3.2 (0.5)	4.0 (3.7)	0.9 (1.6)	5.8 (2.5)	1.9 (0.6)	4.1 (2.6)	2.7	0.0	9.2

There was weak evidence that the pattern of DO over time in the zones was not consistent by depth, although T*Z*D Pillia's trace P = 0.295 for the multivariate test (Appendix 3). Fig. 49 shows that there was no difference in DO by depth within zone 2 on any sampling occasion or within zone 3 on the first three sampling occasions. However, in April 2000 there was a large difference in DO in zone 3 with an average of 8.0 mg/l on the surface and 2.6 mg/l on the bottom. It should be noted that DO measurements were not available for February and June 2000.

The first component of PCA accounted for 55 % of the variation in the data and described turbidity, volatile SS and NO_x-N having a negative relationship with salinity, SiO_4-Si and chlorophyll. The second component was derived solely from fixed SS and accounted for 21 % of the variation (Appendix 4).

Table 22 provides average values of water quality parameters, for each sampling occasion, in surface waters within the Nelson Bay River River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given.

Water quality measured at the surface is likely to be representative of all depths in the lower reaches (zone 2 and 3) of the estuary. The level of the main water quality parameters were generally low, although turbidity was medium to high on most sampling occasions with a median value of 5.2 NTU. High turbidity values are likely to be associated with tannin rich waters. The median concentrations for chlorophyll, NO_x-N and PO_4-P were, 0.0, 7 and 2 µg l^{-1}, respectively. These values suggest that the Nelson Bay River is a comparatively healthy estuary.

3.1.22 Arthur River

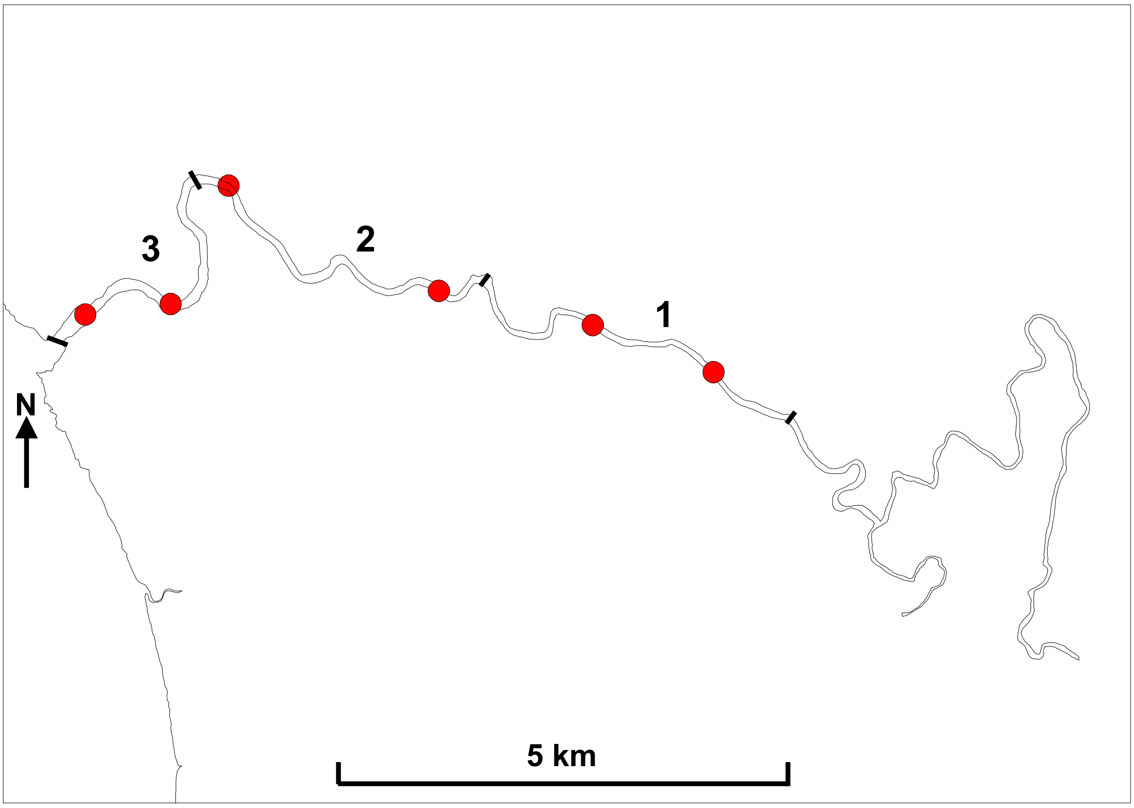

Fig. 50. Arthur River showing fixed sampling sites and zones.

The Arthur River is a large open microtidal river (Edgar *et al.* 1999). The estuary is relatively deep, being approximately 10 m in depth within most of the study region. Within zones 1 and 2, the river banks are heavily vegetated by forest which becomes more open as the river approaches the mouth. The estuary was open on all sampling occasions, although (as occurred in the Pieman River) an extensive sand barrier that appeared to severely limit flow into and out of estuary was present during April 2000. Edgar *et al.* (1999) identified the Arthur River estuary as being of high conservation significance. The National Land and Water Resources Audit identified the Nelson Bay River estuary as being a near pristine, wave dominated estuary (NLWRA 2002).

The pattern of salinity over time within the zones was not consistent by depth (Appendix 3). Fig. 51 shows that the estuary was totally fresh at all depths during August 1999 and June 2000 (winter), with the exception of zone 3 in the June 2000 sample when the average bottom salinity was 5.3 ppt. On all other sampling occasions the estuary was vertically stratified in all zones. The depth of the halocline ranged from approximately 3 to 6 m between sampling events. On any one sampling occasion there was little difference in average salinity between zones within the top 2 m, the largest difference recorded being less than 2ppt. The maximum average surface salinity was 2.2 ppt in zone 1 and 4.2 ppt in zones 2 and 3. The maximum average bottom salinity was between 31.3 and 32.0 ppt within the zones. On any one sampling occasion, the pattern of salinity by depth between zones was generally similar. Salinity values for depths other than the surface are not shown for February 2000 (missing data).

The pattern of temperature over time was not consistent by both zone and depth, (although T*Z Pillia's trace, P = 0.441 for the multivariate test) (Appendix 3). Fig. 51 shows that there was little difference in temperature between zones and depth during the cooler period of the year (August & October 1999, June 2000) and was within 0.5 °C on any one of these sampling occasion. However, in December 1999, the average temperature on the surface was between 2.5 and 4.5 °C higher than on the bottom within the zones. In contrast, the average temperature on the bottom was between 2.0 and 3.0 °C higher than on the surface in April 2000. It is also likely that a relatively large difference in temperature by depth occurred in February 2000 (missing data). Average temperature in any zone ranged from 8.8 to 19.9 °C on the surface and 8.7 to 17.3 °C on the bottom.

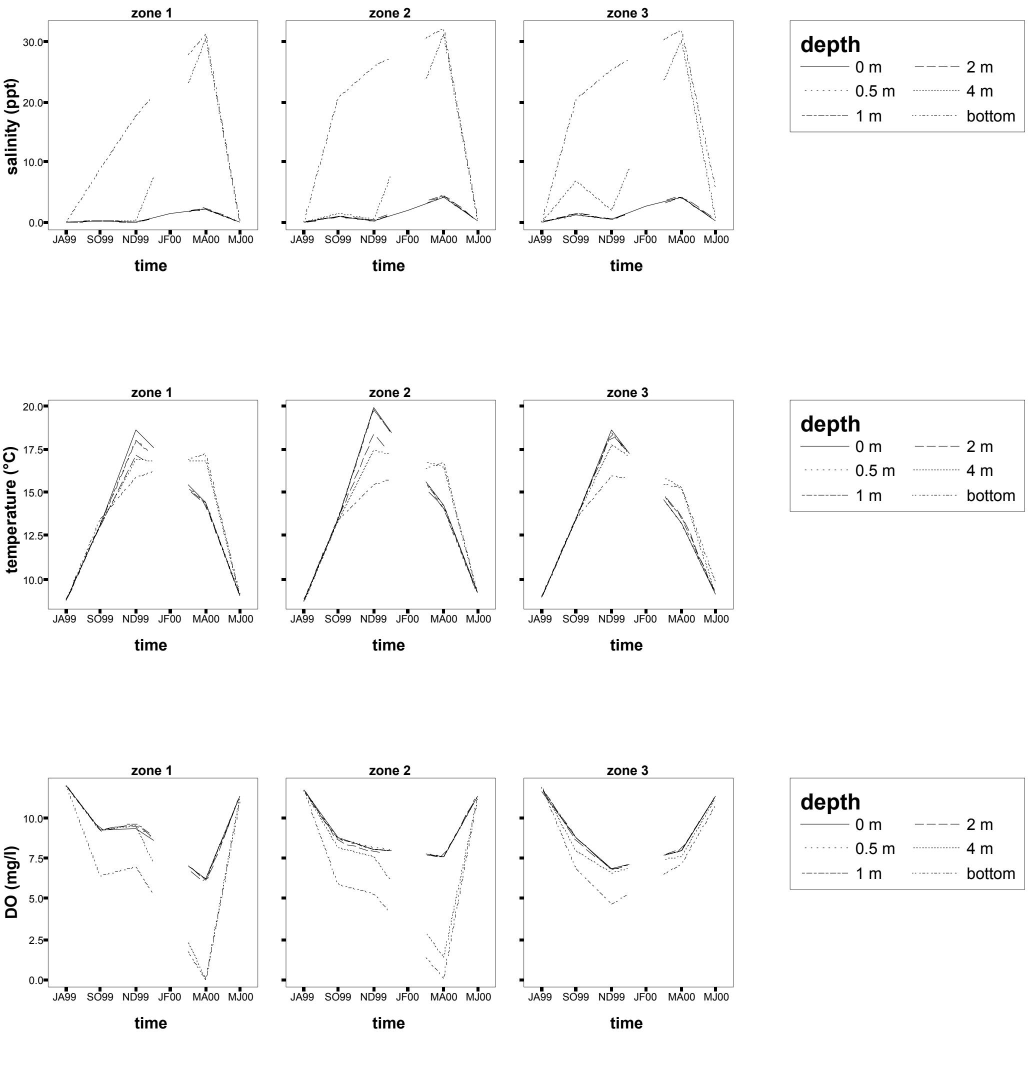

Fig. 51. Average salinity, temperature and DO, by zone and depth, Arthur River (JA99 – MJ00)

Table 23. Average values (n=6), yearly median and range (n= 30 or 36) for water quality parameters of surface waters, Arthur River (figure in parenthesis is the standard error)

		Sample						Median	Range	
Parameter	**Units**	**JA 99**	**SO 99**	**ND 99**	**JF 00**	**MA 00**	**MJ 00**	**99 / 00**	**Min**	**Max**
Salinity	ppt	0.0 (0.0)	0.8 (0.5)	0.2 (0.2)	2.0 (0.7)	3.5 (1.1)	0.1 (0.1)	0.3	0.0	4.7
Temperature	°C	8.8 (0.1)	13.4 (0.3)	19.1 (0.9)		14.0 (0.9)	9.1 (0.1)	13.3	8.7	20.8
Dissolved O_2	mg l^{-1}	11.8 (0.5)	9.0 (0.2)	8.1 (1.4)		7.3 (0.9)	11.4 (0.1)	9.1	5.9	12.4
Turbidity	NTU	10.5 (0.6)	5.2 (0.9)	8.2 (0.5)	2.5 (0.2)	2.9 (0.5)	4.3 (0.3)	4.5	2.1	11.3
Chlorophyll *a*	µg l^{-1}	0.0 (0.0)	0.1 (0.2)	0.0 (0.0)	0.6 (0.5)	0.1 (0.2)	0.0 (0.0)	0.0	0.0	1.3
NO_x-N	µg l^{-1}	39 (1)	17 (3)	10 (2)	5 (1)	9 (3)	20 (1)	13	4	39
PO_4-P	µg l^{-1}	3 (1)	1 (0)	1 (0)	2 (1)	0 (0)	1 (1)	1	0	5
SiO_4-Si	µg l^{-1}	70 (10)	530 (130)	320 (110)	1950 (10)	3140 (240)	210 (10)	425	60	3430
Total SS	mg l^{-1}	8.9 (0.2)	2.5 (0.8)	6.7 (0.6)	3.4 (1.0)	2.9 (0.7)	2.9 (0.5)	3.4	1.8	9.3
Volatile SS	mg l^{-1}	3.2 (0.1)	2.1 (0.3)	2.6 (0.3)	1.5 (0.0)	1.3 (0.5)	1.5 (0.1)	1.7	0.3	3.4
Fixed SS	mg l^{-1}	5.7 (0.2)	0.4 (0.8)	4.2 (0.4)	1.9 (1.0)	1.6 (0.3)	1.4 (0.4)	1.8	0.0	5.9

There was weak evidence that the pattern of DO over time within the zones was not consistent by depth (although T*D*Z Pillia's trace, P = 0.499 for the multivariate test) (Appendix 3). When there was no halocline (*ie.* winter), DO levels between the surface and bottom within any one zone were within 0.5 mg/l (Fig. 51). However, when the estuary was stratified during low flows, DO levels on the bottom were significantly lower than the surface. This was most evident in April 2000 when the water below approximately 3 m in depth within zones 1 and 2 became anoxic. During this time average DO levels in the surface waters were between 6.0 and 7.7 mg/l. Average DO in any zone ranged from 6.3 to 12.0 mg/l on the surface and 0.0 to 12.0 mg/l on the bottom.

The first component of PCA accounted for 57 % of the variation in the data and described turbidity, suspended solids, NO_x-N, PO_4-P and DO being negatively related with salinity and SiO_4-Si (Appendix 4). These relationships were similar to those described for Nelson Bay River (although DO was not included in the analysis for Nelson Bay River). Temperature comprised the second component and accounted for 20 % of the variation.

Table 23 provides average values of water quality parameters, for each sampling occasion, in surface waters within the Arthur River estuary. Minimum, maximum and the median value for the year July 1999/June 2000 are given. Given the stratified nature of the estuary, water quality in surface waters will be unrepresentative of conditions at depths greater than 2 - 4 m, except during winter when the estuary was entirely fresh. Future monitoring of water quality in this estuary should include characterisation of turbidity and nutrients in bottom water.

The level of the main water quality parameters were generally low, although turbidity was medium to high on most sampling occasions with a median value of 4.5 NTU. However, as suspended solid values are relatively low, elevated turbidity levels are likely to be associated with the tannin rich waters common in west coast rivers. The median concentrations for chlorophyll, NO_x-N and PO_4-P were, 0.0, 13 and 1 µg l^{-1}, respectively. These values suggest that, from a water quality perspective of surface waters, the Arthur River estuary is a comparatively healthy estuary.

4. Discussion

Statistical analysis (ANOVA)

Repeated measures ANOVA was found to be a successful statistical approach to determine differences in the physio-chemical nature of the estuaries over time and by zone and depth. Importantly, the often lack of the pattern in environmental parameters throughout each system highlighted the high degree of variability that can occur in many of the estuaries over time. Detection of significant differences was used to determine how to best group data for graphical representation.

However, many of the effects recorded by depth or zone during any one sampling event (particularly temperature and DO) are unlikely to be biologically significant, as only very small differences were observed. This "over sensitive" nature of repeated measures ANOVA may be attributed to some parameters showing strong dependence though time (Mauchly's statistic), resulting in increases in significant results (Type I errors) for the univariate test, or small sample sizes, causing Type II errors for the multivariate test. Often the significance values from the two tests disagreed, emphasising the 'borderline' nature of the test result.

Physical variation

Climatic conditions during the study period were characterised by relatively low rainfall across most of Tasmania, particularly during much of summer and autumn 2000. However, sampling was also undertaken following some large flood events. Significant flooding occurred on the central north coast (Don and Mersey Rivers, Port Sorell) in early August 1999 and on the north-east coast (Ansons Bay, Grants Lagoon, Douglas River) in mid January 2000. Heavy rainfall also preceded sampling in the south-east (Browns and Catamaran Rivers, Cockle Creek) in mid July 1999. Therefore, for most estuaries, sampling covered a broad range of conditions that would usually only be experienced over a longer time scale.

Salinity data from the study confirmed the highly variable nature of estuarine systems, with salinity profiles that often appear to be unique to each estuary (or estuarine type). Some vertical stratification was seen in most estuaries and was very distinct in river estuaries, particularly the large, deep estuaries on the west coast (Arthur and Pieman) and small, east coast river estuaries (Douglas, Meredith, Browns and Catamaran). The upstream section of Ansons Bay was also highly stratified. The estuaries that were not vertically stratified were generally open, marine inlets (East Inlet, Port Sorell, Great Swanport, Little Swanport and Cloudy Bay) or shallow, low salinity estuaries (Boobyalla Inlet and Nelson Bay). However, while not all estuaries showed vertical stratification, salinity differences along the length of the estuary were recorded for all the study estuaries. The greatest vertical stratification and horizontal variation was seen in the upper sections of each estuary (zone1).

For most estuaries (15 from 22), salinity ranges of over 30 ppt were recorded over the 12 months of the study. Two marine inlets, East Inlet and Cloudy Bay Lagoon, were the only estuaries where the recorded salinity range was less than 5 ppt. In Grants Lagoon, Great Swanport and Little Swanport, the salinity range was less than 8 ppt.

Few estuaries showed thermal stratification reflecting the generally shallow nature of most of the estuaries, particularly at low tide when sampling was conducted. Of those estuaries where significant temperature differences by depth were observed, the thermocline was generally not a consistent feature at all sampling events. When thermal stratification did occur, it tended to be associated with a distinct halocline; the more saline bottom water being warmer than the surface water of lower salinity. Similar to salinity, temperature stratification was most evident in the river estuaries on the west and east coasts; mainly the Arthur, Pieman, Douglas, Meredith and Catamaran Rivers and the upstream section of Ansons Bay. Short term thermal stratification, associated with a flood event, was also observed in Grants Lagoon, although in this instance the less saline surface water was warmer than the bottom water.

In estuaries where significant thermal stratification occurred, when stratification was evident the temperature difference between surface and bottom water ranged from 4 to 10 °C. However, on most sampling occasions and for all other estuaries, the temperature difference over depth was usually less than 1 or, at most, 2 °C. Therefore, in most estuaries and on most sampling occasions temperature differences by depth are unlikely to be biologically significant. For all estuaries, temperature differences between the zones were relatively small, 1 to 2 degrees, with the largest differences between the mouth and head of any estuaries on a single sampling occasion being less than 4 °C. Some open, marine inlets (East Inlet, Port Sorell, Cloudy Bay Lagoon) tended to have higher temperature at the head of the estuary during the warmer period of the year, suggesting reduced flushing and water movement in this region of these estuaries.

Major differences (*i.e.* > 2 mg/l) in dissolved oxygen concentrations between surface and bottom water was only recorded from five estuaries; the Pieman, Arthur, Browns and Catamaran Rivers and Ansons Bay. Low oxygen concentrations that are likely to be biologically significant (*i.e.* less than 5 mg/l) were recorded from Duck Bay, East Inlet, Ansons Bay and the Douglas and Arthur Rivers on some sampling occasions. From all samples, DO levels in surface water were greater than 7 mg/l on over 90% of occasions and over 8 mg/l on 75% of occasions.

Correlations

For most estuaries, Principal Components Analysis poorly described the total variation in the data from surface waters (Appendix 4). The first component captured greater than 50% of the variation in only five estuaries; Duck Bay, Port Sorell and the Mersey, Nelson Bay and Arthur Rivers. The first two components captured greater than 75% of the variation in only five estuaries; Port Sorell, the Don, Mersey, Nelson Bay and Arthur Rivers.

Not suprisingly, the first or second component in PCA frequently described a positive relationship between turbidity and suspended solids. This component often incorporated a negative relationship with salinity, particularly in the more degraded estuaries on the north coast. The second, and third, components were often represented by a single parameter.

Due to the general lack of a strong correlation between key parameters, both within and between estuaries, no single parameter was clearly identified as a suitable proxy for water quality. Therefore, selection of appropriate water quality parameters for monitoring should be chosen in relation to the perceived threats for each individual estuary and several parameters should be monitored.

Indicator levels

ANZECC (2000) default trigger values for physical and chemical stressors in estuarine waters (slightly disturbed ecosystems) contain no Tasmanian data and, therefore, a precautionary approach is recommend if the ANZECC values are applied to Tasmanian systems. The guidelines recommend that States develop regional specific trigger values to be used in preference to the ANZECC (2000) values. The draft indicator levels derived from this study (Table 1) fulfil the role of regional specific trigger values and provide the first broad-scale assessment for Tasmanian estuaries. However, given data is from surface waters and some vertical stratification occurred in most estuaries, indicator levels should be applied with caution to samples taken from other depths.

The draft indicator levels are based on the likelihood of exceeding these values during a single sampling event, and are referenced against the range of values observed from all estuaries. In contrast to ANZECC guidelines, where a single trigger value is provided, indicator levels are divided into four categories (low, medium, high and very high) that may indicate different ‘pressure’ on the system. Each category may be used to trigger different management responses depending on whether average values from a single sampling event, or, median values over a longer scale (*eg.* yearly) are exceeded. Depending on the scale of future estuarine water quality studies, alternative indicator levels should be based on a bio-regional or estuary (including location within estuary) scale.

Although ANZECC (2000) suggests turbidity is not a very useful indicator for estuarine and marine waters, Ward *et. al.* (1998) promoted its value as an indicator due to ease and speed of measurement in the field. ANZECC (2000) guidelines provide a range of default trigger values for estuaries (0.5 to 10 NTU) due to site specificity and regional variability. This range encompasses the low (0 to 4 NTU) and medium (4.1 to 10 NTU) indicator levels proposed for Tasmanian estuaries. Fifteen of the 22 estuaries studied had median turbidity values in the low draft indicator level. Estuaries with higher median values were either located within the Boags bio-region (Duck Bay, Don and Mersey Rivers, Port Sorell and Boobyalla Inlet) or had high tannin levels (Nelson Bay and Arthur Rivers).

Average and median chlorophyll concentrations were very low for most estuaries. This is reflected by the low draft indicator level of 2 $\mu g\ l^{-1}$, which is significantly lower than the ANZECC trigger value of 4 $\mu g\ l^{-1}$. Of the 22 estuaries, only two (Ansons Bay and Browns River) had a median concentration of greater than 2 $\mu g\ l^{-1}$. Fourteen of the estuaries had median values of less than 1 $\mu g\ l^{-1}$ including six with a median value of 0 $\mu g\ l^{-1}$. The low indicator level was exceeded on at least half of the sampling occasions in four estuaries; the Don, Meredith and Browns Rivers and Ansons Bay.

A broad range of NO_x-N concentrations were recorded in estuaries around the State. Three estuaries within the Boags bio-region, Duck Bay, Don River and Boobyalla Inlet, recorded both median values, and average values on at least half the sampling occasions, within the very high indicator level. In addition, average NO_x-N concentrations within the Black and Mersey River estuaries were always in the medium to very high range. Fifteen of the estuaries had median values within the low indicator level of 20 $\mu g\ l^{-1}$ (which is slightly higher than the ANZECC trigger value of 15 $\mu g\ l^{-1}$). However, the medium to high NO_x-N values recorded require further investigation to differentiate between anthropogenic and natural riverine input (*eg.* ANZECC default trigger values are 190 $\mu g\ l^{-1}$ for Tasmanian upland rivers).

Similar to NO_x-N, a broad range of PO_4-P concentrations were recorded from around the State. Most estuaries within the Boags bio-region and Ansons Bay tended to have average concentrations within the medium to very high range. In contrast, all other estuaries had average and median values within the low indicator level of 5 $\mu g\ l^{-1}$ (which corresponds to the ANZECC trigger value). The exceptions to this within the other bio-regions were Browns River, which generally had PO_4-P concentrations above the high level, and Earlham and Cloudy Bay Lagoons which were generally within the medium range. Half the estuaries had median values of less than 5 $\mu g\ l^{-1}$; the Pieman and Arthur Rivers having median values of less than 2 $\mu g\ l^{-1}$.

Health status – water quality

Edgar *et al.* [1999] recognised nine major indirect threats to the ecosystem structure and function of Tasmanian estuaries. These were (i) increased siltation from land clearance and urban and rural runoff, (ii) increased nutrient loads from sewage and agricultural fertilisers, (iii) urban effluent, (iv) modification of water flow through dams and weirs, (v) marine farms, (vi) foreshore development and dredging, (vii) acidification and heavy metal pollution, (viii) introduced marine pests, and (ix) long-term climate change. The first four of these threats are likely to manifest as distinct changes to water quality; specifically, by increases in turbidity, algal blooms associated with increased nitrogen and phosphate concentrations, reduced oxygen levels and/or altered salinity profiles.

Many estuaries on the north coast (Boags bioregion) were relatively unhealthy, with elevated turbidity, nitrogen and phosphorus concentrations, particularly the Duck Bay and Don River estuaries. Estuaries in the north-east, Boobyalla Inlet, Little Musselroe River and Ansons Bay, showed high nitrogen or chlorophyll concentrations and require further study to determine susceptibility to eutrophication. In comparison, estuaries in other regions, were generally healthy, with indicator levels in the low to medium range. The exceptions to this were Browns and Meredith River and, on occasion, the Douglas Rivers. Very low oxygen concentrations in bottom waters, associated with a salt wedge, occurred in some estuaries, specifically the Arthur River and Ansons Bay.

Community monitoring

Most community groups measure turbidity use the 'Waterwatch Turbidity Tube', which does not measure turbidity below 7 NTU (Ward 2000). This corresponds to detection of the draft indicator level in the medium range. Only samples from Duck Bay and the Don River had regular average turbidity,k or recorded a yearly median value above the minimum detection limit. Boobyalla Inlet, and the Mersey and Arthur Rivers recorded average turbidity above 7 NTU on more than one occasion while Port Sorell, and the Black, Douglas, Meredith, Pieman and Nelson Bay Rivers each exceeded this level on one sampling occasion.

Ward (2000) makes reference to instrumentation available to community groups for the detection of nitrate having a minimum detection limit of 50 $\mu g\ l^{-1}$ and emphasises that environmentally significant concentrations may be much lower than this level. A concentration of nitrate of 50 $\mu g\ l^{-1}$ corresponds to detection of the draft indicator level for NO_x-N (nitrite and nitrate combined) in the high or very high range. Only samples from Duck Bay, the Black, Don, Mersey and Douglas Rivers and Boobyalla Inlet had average NO_x-N values above 50 $\mu g\ l^{-1}$ on at least half the sampling occasions. Port Sorell, and the Meredith and Browns River had very high NO_x-N on one sampling occasion.

Sampling methods for reactive phosphorus (PO_4-P) commonly utilised by community groups have a minimum detection limit of 15 $\mu g\ l^{-1}$ (Ward 2000). This value corresponds to detection of the draft indicator level for PO_4-P in the high range. Of the estuaries in this study, only samples from Duck Bay and Browns River regularly had average concentrations or recorded a yearly median value above the minimum detection limit. An average value above 15 $\mu g\ l^{-1}$ was recorded on one sampling occasion for each of East Inlet, Don River, Port Sorell and Little Musselroe River.

For most of the estuaries in this study, average values for turbidity, nitrate and phosphate were below the detection limit of sampling equipment commonly used by community groups. As such, it may be argued there is little to be gained from monitoring parameters that are persistently less than the detection limit of the instruments in use. However, for some estuaries, concentrated sampling effort within the upper estuary (where levels would be expected to be highest and most likely to show initial impact) may be justified under the objective of providing early detection of change in indicator levels. Notwithstanding this, a sampling regime in the upper estuary would need to account for the greater spatial and temporal variability of most parameters within this part of the estuary.

Future monitoring and research

A primary aim of this study was to establish baseline water quality data from as many estuaries as possible. Therefore, the sampling regime was a compromise to provide both a reasonable temporal (*i.e.* sampling ever 2 months over one year) and spatial (*i.e.* 22 estuaries) coverage. In hindsight, for some estuaries, spatial coverage within the estuary was not as widespread as was desirable, due to accessibility and/or the extra time needed for sampling. This was most apparent for the upper reaches of systems that have a distinct riverine input at the head of the estuary. Ideally water quality sampling should encompass the region with the uppermost incursion of some saline water. Environmental monitoring that includes the upstream extent of salt water (in bottom water) would be particularly beneficial for systems were altered flow regimes are in effect or proposed. We recommend that mapping the location of the salinity minimum (and thus the true extent of estuarine waters) be undertaken as part of ongoing monitoring of estuarine systems. Importantly, this is a parameter that is easily monitored by any organisation with access to a salinity meter (*i.e.* community groups) , although physical access may be difficult in some estuaries.

To minimise the marine influence of samples, all sampling was conducted as close as possible to the time of low tide. Given the daily tidal variation for much of Tasmania is only 1 metre it is unlikely that parameters such as nutrient concentrations would vary greatly between tides, especially in marine inlets such as Great Swanport or Little Swanport. In contrast, the north of the State has tidal variation of approximately 3 metres and water quality parameter concentrations may be significantly different between tides in some estuaries (*eg.* Duck Bay, Black and Don Rivers, Boobyalla Inlet). Ideally, future water quality monitoring in these estuaries should aim to determine variation over these smaller temporal scales.

This water quality study successfully fulfilled specific objectives of SoE and ANZECC. Regional specific indicator levels have been determined and baseline data collected that allow for regional and long-term comparison. Importantly, clearly defined sampling sites and sampling protocols will allow repetition of sampling and thus, meaningful comparison over time. However, a ‘one off’ broad-scale study such as this simply provides an assessment of the current status of these estuarine systems. To track changes in the health status of these estuaries a monitoring program needs to be established that provides water quality data for comparison to the baseline study. As a minimum requirement, we recommend that comparative broad-scale assessments be conducted every five years, with the health assessment linked to the SoE reporting cycle. Funding is likely to dictate that monitoring programs over smaller temporal scales are determined by political or economic importance and are thus estuary specific.

Government or research organisations are most likely to have the expertise and resources to conduct long term water quality monitoring for the purpose of estuarine health assessment. Importantly, these groups may have direct links to recognised reporting structures such as State of Environment and are able to channel results to specific management responses. However, obtaining dedicated funding for long-term monitoring can be difficult, especially when determining trends in health status may be equally long-term. Acquiring resources for monitoring of near pristine systems or estuaries with a perceived low economic value is also problematic.

While we have provided the baseline data and indicator levels for long term monitoring of water quality for estuarine health assessment, as recommended by ANZECC [2000] and SoE [Ward *et al.* 1998], the next, and perhaps greater, challenge is to procure the resources and coordinate its undertaking and reporting.

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Appendices

Appendix 1. Sampling locations (AGD 66) for each site, as recorded on the first sampling occasion at each estuary.

Estuary	Zone	Latitude		Longitude	
Ansons Bay	1	41	3.355	148	14.623
Ansons Bay	1	41	3.364	148	14.386
Ansons Bay	2	41	3.096	148	15.062
Ansons Bay	2	41	3.325	148	15.020
Ansons Bay	3	41	2.822	148	16.630
Ansons Bay	3	41	2.862	148	16.171
Arthur River	1	41	3.165	144	44.004
Arthur River	1	41	3.494	144	45.017
Arthur River	2	41	2.325	144	41.045
Arthur River	2	41	2.951	144	42.750
Arthur River	3	41	3.111	144	39.921
Arthur River	3	41	3.065	144	40.581
Black River	1	40	50.750	145	18.184
Black River	1	40	50.803	145	18.115
Black River	2	40	50.584	145	18.553
Black River	2	40	50.807	145	18.492
Black River	3	40	50.196	145	18.953
Black River	3	40	50.312	145	18.745
Boobyalla Inlet	1	40	52.833	147	53.337
Boobyalla Inlet	1	40	52.666	147	53.445
Boobyalla Inlet	2	40	52.609	147	52.945
Boobyalla Inlet	2	40	52.820	147	53.033
Boobyalla Inlet	3	40	52.197	147	52.883
Boobyalla Inlet	3	40	52.321	147	52.839
Browns River	1	42	58.724	147	19.157
Browns River	1	42	58.477	147	18.955
Browns River	2	42	58.693	147	19.424
Browns River	2	42	58.777	147	19.347
Browns River	3	42	58.630	147	19.683
Browns River	3	42	58.466	147	19.489
Catamaran River	1	43	33.429	146	52.767
Catamaran River	1	43	33.479	146	52.740
Catamaran River	2	43	33.343	146	53.089
Catamaran River	2	43	33.355	146	52.959
Catamaran River	3	43	33.235	146	53.389
Catamaran River	3	43	33.240	146	53.202
Cloudy Bay Lagoon	1	43	25.859	147	13.793
Cloudy Bay Lagoon	1	43	25.973	147	13.429
Cloudy Bay Lagoon	2	43	25.929	147	13.050
Cloudy Bay Lagoon	2	43	25.974	147	12.640
Cloudy Bay Lagoon	3	43	26.097	147	12.058
Cloudy Bay Lagoon	3	43	25.874	147	12.115
Cockle Creek	1	43	35.190	146	52.686
Cockle Creek	1	43	35.213	146	52.584
Cockle Creek	2	43	34.926	146	53.129
Cockle Creek	2	43	35.028	146	52.991
Cockle Creek	3	43	34.959	146	53.475
Cockle Creek	3	43	34.915	146	53.280
Don River	1	41	10.465	146	19.275
Don River	1	41	10.551	146	19.433
Don River	3	41	9.722	146	19.958
Don River	3	41	9.799	146	19.874
Douglas River	1	41	46.611	148	16.043
Douglas River	1	41	46.660	148	15.988
Douglas River	2	41	46.774	148	16.171
Douglas River	2	41	46.665	148	16.076
Douglas River	3	41	46.838	148	16.262
Douglas River	3	41	46.824	148	16.226
Duck Bay	1	40	50.057	145	7.307
Duck Bay	1	40	50.364	145	7.281
Duck Bay	2	40	49.306	145	6.940
Duck Bay	2	40	49.649	145	7.490
Duck Bay	3	40	48.494	145	6.714
Duck Bay	3	40	48.873	145	6.831

Estuary	Zone	Latitude		Longitude	
Earlham Lagoon	1	42	38.950	147	56.282
Earlham Lagoon	1	42	38.894	147	56.117
Earlham Lagoon	2	42	39.147	147	56.726
Earlham Lagoon	2	42	39.007	147	56.386
Earlham Lagoon	3	42	39.344	147	57.307
Earlham Lagoon	3	42	39.199	147	56.934
East Inlet	1	40	47.987	145	16.804
East Inlet	1	40	48.073	145	16.705
East Inlet	2	40	47.663	145	16.622
East Inlet	2	40	47.778	145	16.749
East Inlet	3	40	47.107	145	16.738
East Inlet	3	40	47.233	145	16.589
Grants Lagoon	1	41	15.275	148	17.514
Grants Lagoon	1	41	15.045	148	17.353
Grants Lagoon	2	41	15.039	148	17.928
Grants Lagoon	2	41	15.181	148	17.817
Grants Lagoon	3	41	15.077	148	18.091
Grants Lagoon	3	41	15.164	148	18.007
Great Swanport	1	42	4.322	148	9.340
Great Swanport	1	42	3.982	148	9.178
Great Swanport	2	42	4.815	148	11.018
Great Swanport	2	42	4.884	148	9.873
Great Swanport	3	42	5.162	148	13.536
Great Swanport	3	42	4.918	148	12.455
Little Musselroe River	1	40	46.433	148	2.520
Little Musselroe River	1	40	46.474	148	2.672
Little Musselroe River	2	40	46.125	148	2.333
Little Musselroe River	2	40	46.284	148	2.465
Little Musselroe River	3	40	45.871	148	2.219
Little Musselroe River	3	40	45.985	148	2.055
Little Swanport	1	42	20.147	147	57.893
Little Swanport	1	42	20.267	147	57.690
Little Swanport	2	42	19.460	147	58.697
Little Swanport	2	42	19.841	147	58.485
Little Swanport	3	42	18.637	147	59.203
Little Swanport	3	42	19.098	147	59.057
Meredith River	1	42	6.831	148	3.955
Meredith River	1	42	6.811	148	3.917
Meredith River	2	42	6.751	148	4.188
Meredith River	2	42	6.785	148	4.049
Meredith River	3	42	6.735	148	4.361
Meredith River	3	42	6.717	148	4.246
Mersey River	1	41	13.140	146	22.726
Mersey River	1	41	13.422	146	23.076
Mersey River	2	41	12.012	146	21.716
Mersey River	2	41	12.270	146	21.985
Mersey River	3	41	10.993	146	21.900
Mersey River	3	41	11.432	146	22.082
Nelson Bay River	2	41	8.287	144	40.873
Nelson Bay River	2	41	8.368	144	40.839
Nelson Bay River	3	41	8.377	144	40.603
Nelson Bay River	3	41	8.399	144	40.754
Pieman River	1	41	38.279	145	4.004
Pieman River	1	41	39.069	145	4.506
Pieman River	2	41	37.193	145	0.011
Pieman River	2	41	37.059	145	2.005
Pieman River	3	41	39.470	144	55.999
Pieman River	3	41	39.009	144	57.044
Port Sorell	1	41	12.279	146	35.261
Port Sorell	1	41	12.874	146	35.134
Port Sorell	2	41	10.864	146	34.528
Port Sorell	2	41	11.711	146	34.572
Port Sorell	3	41	9.361	146	33.385
Port Sorell	3	41	9.887	146	33.921

Appendix 2. Date and time of each sampling occasion by estuary.

Estuary	Sample	Date	Time Start	Time Finish
Ansons Bay	1	21-Jul-99	14.59	15.45
	2	07-Sep-99	8.59	10.03
	3	17-Nov-99	6.40	7.30
	4	18-Jan-00	9.14	9.55
	5	14-Mar-00	7.19	7.57
	6	30-May-00	7.58	8.39
Arthur River	1	11-Aug-99	15.27	16.21
	2	27-Oct-99	16.40	17.50
	3	06-Dec-99	15.29	16.38
	4	09-Feb-00	5.29	6.38
	5	18-Apr-00	12.12	13.33
	6	20-Jun-00	15.02	15.50
Black River	1	11-Aug-99	6.56	8.08
	2	26-Oct-99	5.36	6.39
	3	05-Dec-99	16.19	17.24
	4	08-Feb-00	18.19	19.24
	5	18-Apr-00	5.52	7.06
	6	19-Jun-00	17.18	18.08
Boobyalla Inlet	1	21-Jul-99	11.26	12.36
	2	07-Sep-99	14.17	15.14
	3	17-Nov-99	11.22	12.19
	4	18-Jan-00	14.04	14.51
	5	14-Mar-00	11.52	12.44
	6	30-May-00	12.49	13.36
Browns River	1	12-Jul-99	12.13	13.04
	2	10-Sep-99	13.39	14.36
	3	15-Nov-99	16.23	17.16
	4	13-Jan-00	19.01	19.48
	5	08-Mar-00	13.36	14.32
	6	23-May-00	7.09	8.16
Catamaran River	1	13-Jul-99	11.14	11.49
	2	24-Sep-99	8.39	9.11
	3	22-Nov-99	12.07	12.36
	4	07-Jan-00	12.21	12.46
	5	17-Mar-00	10.02	10.35
	6	26-May-00	8.35	9.07
Cloudy Bay Lagoon	1	28-Jul-99	11.03	13.28
	2	21-Sep-99	9.27	11.55
	3	25-Nov-99	13.00	14.27
	4	14-Jan-00	8.21	8.59
	5	18-Mar-00	14.25	16.16
	6	24-May-00	8.27	10.11
Cockle Creek	1	13-Jul-99	12.35	13.42
	2	24-Sep-99	10.42	11.38
	3	22-Nov-99	13.18	13.57
	4	07-Jan-00	13.59	14.38
	5	17-Mar-00	11.33	12.12
	6	26-May-00	9.50	10.29
Don River	1	19-Aug-99	11.43	12.26
	2	05-Oct-99	12.00	12.34
	3	03-Dec-99	14.00	14.40
	4	07-Feb-00	8.00	8.40
	5	13-Apr-00	11.36	12.16
	6	13-Jun-00	15.36	16.07
Douglas River	1	15-Jul-99	11.35	12.18
	2	08-Sep-99	9.34	10.24
	3	23-Nov-99	10.33	11.23
	4	17-Jan-00	11.44	12.21
	5	15-Mar-00	7.07	7.48
	6	31-May-00	8.51	9.21
Duck Bay	1	10-Aug-99	12.32	13.34
	2	27-Oct-99	9.21	9.59
	3	06-Dec-99	6.11	6.54
	4	08-Feb-00	8.11	8.54
	5	17-Apr-00	15.52	16.46
	6	20-Jun-00	9.19	9.55

Estuary	Sample	Date	Time Start	Time Finish
Earlham Lagoon	1	15-Jul-99	16.02	16.49
	2	14-Sep-99	16.45	17.42
	3	23-Nov-99	14.47	15.28
	4	12-Jan-00	6.59	7.47
	5	09-Mar-00	16.10	16.55
	6	25-May-00	7.27	8.38
East Inlet	1	10-Aug-99	15.21	16.42
	2	27-Oct-99	7.46	8.20
	3	06-Dec-99	4.29	5.01
	4	08-Feb-00	6.46	7.20
	5	18-Apr-00	7.45	8.36
	6	20-Jun-00	7.45	8.09
Grants Lagoon	1	20-Jul-99	15.04	16.13
	2	06-Sep-99	13.51	14.50
	3	16-Nov-99	14.28	15.30
	4	17-Jan-00	14.15	15.13
	5	13-Mar-00	15.58	16.48
	6	29-May-00	15.06	16.05
Great Swanport	1	22-Jul-99	8.29	9.23
	2	28-Sep-99	13.09	14.17
	3	18-Nov-99	7.59	8.50
	4	19-Jan-00	10.10	11.04
	5	15-Mar-00	9.25	10.10
	6	31-May-00	11.03	11.44
Little Musselroe River	1	21-Jul-99	8.30	9.19
	2	07-Sep-99	11.35	12.25
	3	17-Nov-99	9.01	9.44
	4	18-Jan-00	11.41	12.24
	5	14-Mar-00	9.28	10.10
	6	30-May-00	10.44	11.19
Little Swanport	1	22-Jul-99	10.36	11.12
	2	08-Sep-99	12.21	13.07
	3	18-Nov-99	10.08	10.52
	4	19-Jan-00	13.15	13.44
	5	15-Mar-00	11.20	11.49
	6	31-May-00	13.12	13.41
Meredith River	1	15-Jul-99	13.38	14.20
	2	14-Sep-99	14.09	14.54
	3	23-Nov-99	12.36	13.05
	4	12-Jan-00	9.24	9.56
	5	09-Mar-00	13.45	14.18
	6	25-May-00	10.52	11.40
Mersey River	1	19-Aug-99	9.14	10.28
	2	05-Oct-99	10.30	11.09
	3	03-Dec-99	12.19	13.01
	4	07-Feb-00	6.19	7.01
	5	13-Apr-00	10.07	10.50
	6	14-Jun-00	12.16	13.01
Nelson Bay River	1	11-Aug-99	13.26	14.07
	2	28-Oct-99	6.33	6.58
	3	06-Dec-99	10.51	11.21
	4	09-Feb-00	7.51	8.21
	5	18-Apr-00	16.28	16.58
	6	20-Jun-00	13.05	13.21
Pieman River	1	12-Aug-99	10.57	12.29
	2	28-Oct-99	10.37	12.14
	3	07-Dec-99	9.14	10.54
	4	09-Feb-00	12.14	13.54
	5	19-Apr-00	10.05	11.28
	6	21-Jun-00	11.00	12.15
Port Sorell	1	09-Aug-99	14.07	15.14
	2	04-Oct-99	11.46	12.42
	3	02-Dec-99	12.49	13.47
	4	07-Feb-00	18.49	19.47
	5	12-Apr-00	12.46	13.34
	6	13-Jun-00	13.49	14.33

Appendix 3. Results of repeated measures Analysis of Variance for salinity, temperature and dissolved oxygen.

1. Duck Bay

	Salinity	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	2242.543	2	1121.272	17.796	< 0.01					
Between subjects	DEPTH (D)	840.753	1	840.753	13.344	< 0.025					
Between subjects	Z*D	364.472	2	182.236	2.892	0.132					
Between subjects	Error	378.046	6	63.008							
		Mauchly's W = 0.001; ***P*** < 0.01			**H-F Epsilon** = 0.613		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	880.312	2.451	359.108	11.222	< 0.01	0.987	55.659	4	3	< 0.01
Within subjects	T*Z	463.664	4.903	94.572	2.955	< 0.05	1.860	13.305	8	8	< 0.01
Within subjects	T*D	112.046	2.451	45.707	1.428	0.273	0.956	16.361	4	3	< 0.025
Within subjects	T*Z*D	122.944	4.903	25.077	0.784	0.575	1.415	2.421	8	8	0.116
Within subjects	Error	470.654	14.708	31.999							

	Temperature	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.094	2	0.547	5.382	< 0.05					
Between subjects	DEPTH (D)	0.353	1	0.353	3.469	0.112					
Between subjects	Z*D	0.244	2	0.122	1.202	0.364					
Between subjects	Error	0.610	6	0.102							
		Mauchly's W = 0.007; ***P*** < 0.025			**H-F Epsilon** = 0.853		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	591.203	3.410	173.357	1657.578	< 0.001	1.000	20737.827	4	3	< 0.001
Within subjects	T*Z	4.637	6.821	0.680	6.501	< 0.001	1.678	5.205	8	8	< 0.025
Within subjects	T*D	3.577	3.410	1.049	10.030	< 0.001	0.989	67.693	4	3	< 0.01
Within subjects	T*Z*D	2.891	6.821	0.424	4.052	< 0.01	1.074	1.161	8	8	0.419
Within subjects	Error	2.140	20.462	0.105							

	DO	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.541	2	0.271	5.558	< 0.05					
Between subjects	DEPTH (D)	0.726	1	0.726	14.918	< 0.01					
Between subjects	Z*D	1.267	2	0.633	13.017	< 0.01					
Between subjects	Error	0.292	6	0.049							
		Mauchly's W = 0.210; ***P*** =0.674			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	143.222	4	35.806	434.446	< 0.001	0.996	202.624	4	3	< 0.01
Within subjects	T*Z	5.306	8	0.663	8.047	< 0.001	1.806	9.293	8	8	< 0.01
Within subjects	T*D	0.606	4	0.151	1.837	0.155	0.721	1.935	4	3	0.307
Within subjects	T*Z*D	0.756	8	0.095	1.147	0.369	0.966	0.934	8	8	0.537
Within subjects	Error	1.978	24	0.082							

2. East Inlet

	Salinity	**ANOVA**									
Between subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***					
	ZONE (Z)	4.044	2	2.002	49.926	< 0.001					
	DEPTH (D)	0.014	1	0.014	0.333	0.585					
	Z*D	0.004	2	0.002	0.049	0.952					
	Error	0.243	6	0.041			**MANOVA**				
Within subjects		**Mauchly's W** = 0.002;	***P*** < 0.01		**H-F Epsilon** = 0.696		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	39.781	2.782	14.299	146.252	< 0.001	0.999	1152.519	4	3	< 0.001
	T*Z	6.334	5.564	1.138	11.644	< 0.001	1.962	51.983	8	8	< 0.001
	T*D	0.011	2.782	0.004	0.039	0.986	0.475	0.678	4	3	0.652
	T*Z*D	0.014	5.564	0.003	0.026	1.000	0264	0.152	8	8	0.992
	Error	1.632	16.692	0.098							

	Temperature	**ANOVA**									
Between subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***					
	ZONE (Z)	6.346	2	3.173	26.815	< 0.01					
	DEPTH (D)	0.006	1	0.006	0.051	0.829					
	Z*D	0.043	2	0.022	0.182	0.838					
	Error	0.710	6	0.118			**MANOVA**				
Within subjects		**Mauchly's W** = 0.001;	***P*** < 0.001		**H-F Epsilon** = 0.727		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	153.562	2.908	52.798	246.357	< 0.001	1.000	1735.568	4	3	< 0.001
	T*Z	21.524	5.817	3.700	17.265	< 0.001	1.970	64.828	8	8	< 0.001
	T*D	0.226	2.908	0.078	0.362	0.775	0.596	1.108	4	3	0.486
	T*Z*D	0.320	5.817	0.055	0.257	0.947	0.636	0.467	8	8	0.849
	Error	3.740	17.451	0.214							

	DO	**ANOVA**									
Between subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***					
	ZONE (Z)	4.143	2	2.071	13.703	< 0.01					
	DEPTH (D)	0.0002	1	0.0002	0.001	0.975					
	Z*D	0.002	2	0.001	0.008	0.992					
	Error	0.907	6	0.151			**MANOVA**				
Within subjects		**Mauchly's W** = 0.004;	***P*** < 0.01		**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	59.011	4	14.753	86.611	< 0.001	0.997	254.827	4	3	< 0.001
	T*Z	13.177	8	1.647	9.670	< 0.001	1.321	1.947	8	8	0.183
	T*D	0.002	4	0.0006	0.003	1.000	0.028	0.022	4	3	0.999
	T*Z*D	0.018	8	0.002	0.013	1.000	0.448	0.289	8	8	0.951
	Error	4.088	24	0.170							

3. Black River

	Salinity	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	392.373	2	196.186	11.332	< 0.01					
	DEPTH (D)	524.513	1	524.513	30.296	< 0.01					
	Z*D	227.842	2	113.921	6.580	< 0.05					
	Error	103.876	6	17.313			**MANOVA**				
Within subjects		**Mauchly's W** = 0.002;	***P*** < 0.01		**H-F Epsilon** = 0.957		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	2505.712	3.829	654.454	47.198	< 0.001	0.999	838.459	4	3	< 0.001
	T*Z	120.115	7.657	15.686	1.131	0.380	1.787	8.400	8	8	< 0.01
	T*D	304.376	3.829	79.498	5.733	< 0.01	0.976	31.132	4	3	< 0.01
	T*Z*D	147.039	7.657	19.202	1.385	0.256	1.772	7.761	8	8	< 0.01
	Error	318.534	22.972	13.866							

	Temperature	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	2.820	2	1.410	11.046	< 0.025					
	DEPTH (D)	1.291	1	1.291	10.110	< 0.025					
	Z*D	0.760	2	0.380	2.978	0.126					
	Error	0.766	6	0.128			**MANOVA**				
Within subjects		**Mauchly's W** = 0.001;	***P*** < 0.01		**H-F Epsilon** = 0.882		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	768.876	3.287	233.928	676.034	< 0.001	1.000	7035.598	4	3	< 0.001
	T*Z	3.086	6.574	0.470	1.357	0.278	1.663	4.936	8	8	< 0.025
	T*D	5.608	3.287	1.706	4.931	< 0.01	0.979	34.869	4	3	< 0.01
	T*Z*D	2.966	6.754	0.451	1.304	0.300	1.035	1.072	8	8	0.462
	Error	6.824	19.721	0.346							

	DO	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.420	2	0.210	8.008	< 0.025					
	DEPTH (D)	0.521	1	0.521	19.841	< 0.01					
	Z*D	0.238	2	0.119	4.532	0.063					
	Error	0.158	6	0.026			**MANOVA**				
Within subjects		**Mauchly's W** = 0.037;	***P*** < 0.025		**H-F Epsilon** = 0.894		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	107.725	2.683	40.157	307.420	< 0.001	0.998	782.758	3	4	< 0.001
	T*Z	7.536	5.365	1.405	10.753	< 0.001	1.645	7.711	6	10	< 0.01
	T*D	0.421	2.683	0.157	1.201	0.338	0.804	5.461	3	4	0.067
	T*Z*D	0.375	5.365	0.070	0.536	0.757	1.136	2.192	6	10	0.131
	Error	2.103	16.096	0.131							

4. Don River

	Salinity	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	492.804	1	492.804	45.081	< 0.01					
	DEPTH (D)	49.729	1	49.729	4.549	0.100					
	Z*D	41.616	1	41.616	3.807	0.123					
	Error	43.726	4	10.932							
Within subjects		**Mauchly's W** = 0.001; ***P*** < 0.025			**H-F Epsilon** = 0.756		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	2697.689	3.024	891.990	143.927	< 0.001	1.000	4592.290	4	1	< 0.025
	T*Z	15.683	3.024	5.186	0.837	0.500	0.999	373.966	4	1	< 0.05
	T*D	76.283	3.024	25.223	4.070	< 0.05	1.000	511.709	4	1	< 0.05
	T*Z*D	80.267	3.024	26.540	4.282	< 0.05	1.000	515.091	4	1	< 0.05
	Error	74.974	12.097	6.198							

	Temperature	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	2.704	1	2.704	600.889	< 0.001					
	DEPTH (D)	0.025	1	0.025	5.556	0.078					
	Z*D	0.001	1	0.001	0.222	0.662					
	Error										
Within subjects		**Mauchly's W** = 0.001; ***P*** =0.120			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	463.721	4	115.930	4614.144	< 0.001	1.000	57409.488	4	1	< 0.01
	T*Z	2.224	4	0.556	22.124	< 0.001	0.995	51.270	4	1	0.104
	T*D	0.477	4	0.119	4.751	< 0.025	0.971	8.426	4	1	0.252
	T*Z*D	0.292	4	0.073	2.900	0.056	0.926	3.145	4	1	0.397
	Error	0.402	16	0.025							

5. Mersey River

	Salinity	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1114.813	2	557.407	28.674	< 0.01					
	DEPTH (D)	433.091	1	433.091	22.279	< 0.01					
	Z*D	143.912	2	71.956	3.702	0.090					
	Error	116.636	6	19.439							
Within subjects		**Mauchly's W** = 0.067; ***P*** =0.248			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	1713.443	4	428.361	120.631	< 0.001	0.983	43.815	4	3	< 0.01
	T*Z	336.360	8	42.045	11.840	< 0.001	1.605	4.069	8	8	< 0.05
	T*D	128.443	4	32.111	9.043	< 0.001	0.959	17.736	4	3	< 0.025
	T*Z*D	162.654	8	20.332	5.726	< 0.001	1.604	4.054	8	8	< 0.05
	Error	85.224	24	3.551							

	Temperature	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	2.290	2	1.145	7.962	< 0.025					
	DEPTH (D)	2.054	1	2.054	14.277	< 0.01					
	Z*D	0.067	2	0.034	0.233	0.799					
	Error	0.863	6	0.144							
Within subjects		**Mauchly's W** = 0.071; ***P*** = 0.264			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	674.356	4	168.589	1991.208	< 0.001	0.999	1117.203	4	3	< 0.001
	T*Z	17.256	8	2.157	25.477	< 0.001	1.119	1.270	8	8	0.372
	T*D	6.062	4	1.516	17.901	< 0.001	0.961	18.548	4	3	< 0.025
	T*Z*D	1.750	8	0.219	2.583	< 0.05	0.844	0.730	8	8	0.667
	Error	2.032	24	0.085							

	DO	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	3.472	2	1.736	8.340	< 0.025					
	DEPTH (D)	3.050	1	3.050	14.656	< 0.01					
	Z*D	1.152	2	0.576	2.767	0.141					
	Error	1.249	6	0.208							
Within subjects		**Mauchly's W** = 0.234; ***P*** =0.240			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	29.591	3	9.864	164.965	< 0.001	0.993	179.045	3	4	< 0.001
	T*Z	3.905	6	0.651	10.885	< 0.001	1.616	7.005	6	10	< 0.01
	T*D	2.007	3	0.669	11.190	< 0.001	0.875	9.370	3	4	< 0.05
	T*Z*D	0.718	6	0.120	2.002	0.119	1.172	2.358	6	10	0.111
	Error	1.076	18	0.060							

6. Port Sorell

	Salinity	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	315.362	2	157.681	37.786	< 0.001					
	DEPTH (D)	3.553	1	3.553	0.851	0.392					
	Z*D	1.412	2	0.706	0.169	0.848					
	Error	25.038	6	4.173							
		Mauchly's W = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.541		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	2451.213	2.162	1133.748	388.650	< 0.001	1.000	1843.087	4	3	< 0.001
	T*Z	492.473	4.324	113.890	39.042	< 0.001	1.863	13.594	8	8	< 0.01
	T*D	9.831	2.162	4.547	1.559	0.248	0.342	0.391	4	3	0.807
	T*Z*D	3.569	4.324	0.825	0.283	0.895	0.774	0.632	8	8	0.735
	Error	37.842	12.972	2.917							

	Temperature	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	2.401	2	1.201	18.235	< 0.01					
	DEPTH (D)	0.028	1	0.028	0.428	0.537					
	Z*D	0.004	2	0.002	0.033	0.968					
	Error	0.395	6	0.066							
		Mauchly's W = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.591		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1275.349	2.362	539.932	2484.446	< 0.001	1.000	15561.207	4	3	< 0.001
	T*Z	44.694	4.724	9.461	43.533	< 0.001	1.415	2.419	8	8	0.117
	T*D	0.134	2.362	0.057	0.262	0.807	0.452	0.618	4	3	0.681
	T*Z*D	0.051	4.724	0.011	0.049	0.998	0.888	0.799	8	8	0.621
	Error	3.080	14.172	0.217							

	DO	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.858	2	0.929	9.156	< 0.025					
	DEPTH (D)	0.047	1	0.047	0.462	0.522					
	Z*D	0.079	2	0.039	0.388	0.694					
	Error	0.609	6	0.101							
		Mauchly's W = 0.391;	***P*** =0.497		**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	46.906	3	15.635	193.259	< 0.001	0.994	221.344	3	4	< 0.001
	T*Z	22.569	6	3.761	46.494	< 0.001	1.204	2.523	6	10	0.094
	T*D	0.126	3	0.042	0.518	0.675	0.318	0.623	3	4	0.637
	T*Z*D	0.201	6	0.034	0.415	0.860	0.474	0.517	6	10	0.783
	Error	1.456	18	0.081							

7. Boobyalla Inlet (Ringarooma River)

	ln(Sal+0.1)	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	133.984	2	66.992	110.196	< 0.001					
	DEPTH (D)	0.506	1	0.506	0.832	0.397					
	Z*D	0.140	2	0.070	0.115	0.893					
	Error	3.648	6	0.608			**MANOVA**				
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.001			**H-F Epsilon** = 0.462		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	309.033	2.310	133.799	54.731	< 0.001	1.000	1227.660	5	2	< 0.01
	T*Z	35.061	4.619	7.590	3.105	<0.05	1.858	7.854	10	6	< 0.025
	T*D	0.328	2.310	0.142	0.058	0.960	0.957	8.926	5	2	0.104
	T*Z*D	1.127	4.619	0.244	0.100	0.988	1.399	1.395	10	6	0.355
	Error	33.878	13.858	2.445							

	Temperature	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	7.764	2	3.882	35.836	< 0.001					
	DEPTH (D)	0.020	1	0.020	0.185	0.682					
	Z*D	0.010	2	0.005	0.046	0.955					
	Error						**MANOVA**				
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.001			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	2140.001	5	428.000	4427.589	< 0.001	1.000	195462.59	5	2	< 0.001
	T*Z	3.057	10	0.306	3.163	< 0.01	1.818	6.003	10	6	< 0.025
	T*D	0.053	5	0.011	0.110	0.989	0.763	1.291	5	2	0.491
	T*Z*D	0.022	10	0.002	0.022	1.000	0.725	0.341	10	6	0.936
	Error	2.900	30	0.097							

	DO	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.233	2	0.117	1.759	0.251					
	DEPTH (D)	0.0007	1	0.0007	0.010	0.923					
	Z*D	0.005	2	0.003	0.040	0.961					
	Error	0.398	6	0.066			**MANOVA**				
Within subjects		**Mauchly's W** = 0.001; ***P*** < 0.001			**H-F Epsilon** = 0.966		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	58.606	3.985	14.708	223.686	< 0.001	1.000	13794.090	4	3	< 0.001
	T*Z	2.123	7.969	0.266	4.052	< 0.01	1.685	5.350	8	8	< 0.025
	T*D	0.031	3.985	0.008	0.118	0.974	0.506	0.767	4	3	0.611
	T*Z*D	0.028	7.969	0.004	0.053	1.000	0.468	0.305	8	8	0.943
	Error	1.572	23.908	0.066							

8. Little Musselroe River

	Salinity	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	635.509	2	317.754	30.474	< 0.01					
	DEPTH (D)	9.753	1	9.753	0.935	0.371					
	Z*D	198.447	2	99.223	9.516	< 0.025					
	Error	62.563	6	10.427			**MANOVA**				
		Mauchly's W = 0.000; ***P*** < 0.01			**H-F Epsilon** = 0.646		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	2375.706	3.232	735.001	129.605	< 0.001	0.998	186.152	5	2	< 0.01
	T*Z	792.710	6.465	122.625	21.623	< 0.001	1.942	20.197	10	6	< 0.01
	T*D	342.139	3.232	105.852	18.665	< 0.001	0.984	24.636	5	2	< 0.05
	T*Z*D	78.948	6.465	12.213	2.153	0.090	1.575	2.225	10	6	0.170
	Error	109.983	19.394	5.671							

	Temperature	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	100.498	2	50.249	53.252	< 0.001					
	DEPTH (D)	1.227	1	1.227	1.301	0.298					
	Z*D	2.954	2	1.477	1.565	0.284					
	Error	5.662	6	0.944			**MANOVA**				
		Mauchly's W = 0.000; ***P*** < 0.001			**H-F Epsilon** = 0.745		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1793.981	3.724	481.692	460.619	< 0.001	1.000	41808.290	5	2	< 0.001
	T*Z	62.891	7.449	8.443	8.074	< 0.001	1.996	306.801	10	6	< 0.001
	T*D	2.139	3.724	0.574	0.549	0.690	0.985	26.162	5	2	< 0.05
	T*Z*D	3.624	7.449	0.487	0.465	0.858	1.224	0.947	10	6	0.554
	Error	23.368	22.346	1.046							

	ln(DO + 0.1)	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.440	2	0.220	11.950	< 0.01					
	DEPTH (D)	0.006	1	0.006	0.306	0.600					
	Z*D	0.012	2	0.006	0.315	0.741					
	Error	0.110	6	0.018			**MANOVA**				
		Mauchly's W = 0.001; ***P*** < 0.001			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	2.215	4	0.554	38.593	< 0.001	0.999	675.902	4	3	< 0.001
	T*Z	0.300	8	0.038	2.617	< 0.05	1.502	3.017	8	8	0.070
	T*D	0.012	4	0.003	0.204	0.934	0.992	90.295	4	3	< 0.01
	T*Z*D	0.022	8	0.003	0.191	0.990	0.997	0.995	8	8	0.503
	Error	0.344	24	0.014							

9. Ansons Bay

	Salinity	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1830.648	2	915.324	129.002	< 0.001					
Between subjects	DEPTH (D)	3861.740	1	3861.740	544.258	< 0.001					
Between subjects	Z*D	999.801	2	499.901	70.454	< 0.001					
Between subjects	Error	42.572	6	7.095							
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.001		**H-F Epsilon** = 0.604			**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	3085.354	3.020	1021.730	45.409	< 0.001	0.989	36.595	5	2	< 0.05
Within subjects	T*Z	235.484	6.039	38.991	1.733	0.170	1.851	7.437	10	6	< 0.025
Within subjects	T*D	691.787	3.020	229.089	10.182	< 0.001	1.000	2575.568	5	2	< 0.001
Within subjects	T*Z*D	529.494	6.039	87.672	3.896	< 0.025	1.882	9.583	10	6	< 0.01
Within subjects	Error	407.672	18.118	22.500							

	Temperature	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	12.187	2	6.093	7.836	< 0.025					
Between subjects	DEPTH (D)	11.281	1	11.281	14.507	< 0.01					
Between subjects	Z*D	14.381	2	7.190	9.246	< 0.025					
Between subjects	Error	4.666	6	0.778							
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.01		**H-F Epsilon** = 1.000			**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	833.127	5	166.625	399.289	< 0.001	1.000	2683.975	5	2	< 0.001
Within subjects	T*Z	25.751	10	2.575	6.171	< 0.001	1.958	28.062	10	6	< 0.001
Within subjects	T*D	23.090	5	4.618	11.066	< 0.001	0.997	116.584	5	2	< 0.01
Within subjects	T*Z*D	12.841	10	1.284	3.077	< 0.01	1.783	4.936	10	6	< 0.05
Within subjects	Error	12.519	30	0.417							

	DO	**ANOVA**					**MANOVA**				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	49.874	2	24.937	48.110	< 0.001					
Between subjects	DEPTH (D)	145.067	1	145.067	279.872	< 0.001					
Between subjects	Z*D	32.008	2	16.004	30.876	< 0.01					
Between subjects	Error	3.110	6	0.518							
Within subjects		**Mauchly's W** = 0.002; ***P*** =0.062		**H-F Epsilon** = 1.000			**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	46.148	5	9.230	13.123	< 0.001	0.995	84.096	5	2	< 0.025
Within subjects	T*Z	39.487	10	3.949	5.614	< 0.001	1.805	5.553	10	6	< 0.025
Within subjects	T*D	88.801	5	17.760	25.252	< 0.001	0.998	174.386	5	2	< 0.01
Within subjects	T*Z*D	19.924	10	1.992	2.833	< 0.025	1.414	1.447	10	6	0.337
Within subjects	Error	21.100	30	0.703							

10. Grants Lagoon

Salinity		ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	3.058	2	1.529	71.019	< 0.001					
Between subjects	DEPTH (D)	3.600	1	3.600	167.232	< 0.001					
Between subjects	Z*D	1.608	2	0.804	37.342	< 0.001					
Between subjects	Error	0.129	6	0.022			**MANOVA**				
Within subjects		**Mauchly's W** = 0.001;	***P*** < 0.025		**H-F Epsilon** = 0.842		**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	228.042	4.208	54.190	6647.389	< 0.001	1.000	4103.244	5	2	< 0.001
Within subjects	T*Z	14.942	8.416	1.775	217.781	< 0.001	1.882	9.569	10	6	< 0.01
Within subjects	T*D	19.096	4.208	4.538	556.636	< 0.001	1.000	2391.712	5	2	< 0.001
Within subjects	T*Z*D	8.569	8.416	1.018	124.891	< 0.001	1.776	4.760	10	6	< 0.05
Within subjects	Error	0.206	25.249	0.008							

Temperature		ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.241	2	0.120	11.115	< 0.025					
Between subjects	DEPTH (D)	5.120	1	5.120	472.615	< 0.001					
Between subjects	Z*D	1.456	2	0.728	67.192	< 0.001					
Between subjects	Error	0.065	6	0.011			**MANOVA**				
Within subjects		**Mauchly's W** = 0.001;	***P*** < 0.05		**H-F Epsilon** = 0.692		**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1324.025	3.462	382.478	7750.390	< 0.001	1.000	24935.188	5	2	< 0.001
Within subjects	T*Z	30.709	6.923	4.436	89.880	< 0.001	1.969	37.864	10	6	< 0.001
Within subjects	T*D	24.363	3.462	7.038	142.615	< 0.001	0.999	797.793	5	2	< 0.01
Within subjects	T*Z*D	6.671	6.923	0.964	19.524	< 0.001	1.201	0.902	10	6	0.579
Within subjects	Error	1.025	20.770	0.049							

DO		ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	4.681	2	2.340	24.508	< 0.01					
Between subjects	DEPTH (D)	0.008	1	0.008	0.086	0.780					
Between subjects	Z*D	0.114	2	0.057	0.599	0.579					
Between subjects	Error	0.573	6	0.096			**MANOVA**				
Within subjects		**Mauchly's W** = 0.004;	***P*** < 0.01		**H-F Epsilon** = 0.796		**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	26.012	3.183	8.171	37.589	< 0.001	0.997	244.261	4	3	< 0.001
Within subjects	T*Z	19.542	6.367	3.069	14.120	< 0.001	1.208	1.525	8	8	0.282
Within subjects	T*D	0.074	3.183	0.023	0.107	0.961	0.623	1.240	4	3	0.488
Within subjects	T*Z*D	0.136	6.367	0.021	0.098	0.997	0.852	0.742	8	8	0.659
Within subjects	Error	4.152	19.100	0.217							

11. Douglas River

	Salinity	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	14.174	2	7.087	2.693	0.146					
	DEPTH (D)	10454.580	1	10454.580	3973.027	< 0.001					
	Z*D	12.633	2	6.316	2.400	0.171					
	Error	15.788	6	2.631			**MANOVA**				
Within subjects		**Mauchly's W** = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.677		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	349.213	3.385	103.158	4.832	< 0.01	0.998	169.206	5	2	< 0.01
	T*Z	63.185	6.770	9.332	0.437	0.863	1.557	2.107	10	6	0.187
	T*D	501.158	3.385	148.043	6.935	< 0.01	1.000	819.622	5	2	< 0.01
	T*Z*D	88.149	6.770	13.020	0.610	0.737	1.784	4.945	10	6	< 0.05
	Error	433.612	20.311	21.348							

	Temperature	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	17.044	2	8.522	6.138	< 0.05					
	DEPTH (D)	168.667	1	168.667	121.489	< 0.001					
	Z*D	6.580	2	3.290	2.370	0.174					
	Error	8.330	6	1.388			**MANOVA**				
Within subjects		**Mauchly's W** = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.600		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	1206.646	3.001	402.017	209.699	< 0.001	1.000	19417.389	5	2	< 0.001
	T*Z	16.075	6.003	2.678	1.397	< 0.269	1.796	5.270	10	6	< 0.05
	T*D	115.234	3.001	38.393	20.023	< 0.001	0.999	459.157	5	2	< 0.01
	T*Z*D	7.678	6.003	1.279	0.667	0.677	1.563	2.146	10	6	0.181
	Error	34.530	18.009	1.917							

	DO	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.589	2	0.294	0.339	0.725					
	DEPTH (D)	83.477	1	83.477	96.250	< 0.001					
	Z*D	2.671	2	1.336	1.540	0.289					
	Error	5.204	6	0.867			**MANOVA**				
Within subjects		**Mauchly's W** = 0.863;	***P*** =0.983		**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	73.711	3	24.570	36.011	< 0.001	0.963	34.552	3	4	< 0.01
	T*Z	7.186	6	1.198	1.755	0.165	0.883	1.318	6	10	0.333
	T*D	26.411	3	8.804	12.903	< 0.001	0.911	13.643	3	4	< 0.025
	T*Z*D	4.274	6	0.712	1.044	0.430	0.649	0.801	6	10	0.591
	Error	12.281	18	0.682							

12. Great Swanport

	Salinity	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	122.001	2	61.001	65.144	< 0.001					
Between subjects	DEPTH (D)	0.569	1	0.569	0.608	0.465					
Between subjects	Z*D	0.448	2	0.224	0.239	0.794					
Between subjects	Error	5.618	6	0.936			**MANOVA**				
		Mauchly's W = 0.000; ***P*** < 0.01			**H-F Epsilon** = 0.748		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	92.571	3.741	24.742	50.578	< 0.001	0.992	52.594	5	2	< 0.025
Within subjects	T*Z	40.081	7.483	5.356	10.949	< 0.001	1.894	10.520	10	6	< 0.01
Within subjects	T*D	0.499	3.741	0.133	0.273	0.882	0.907	3.882	5	2	0.217
Within subjects	T*Z*D	1.064	7.483	0.142	0.291	0.957	1.082	0.707	10	6	0.701
Within subjects	Error	10.982	22.449	0.489							

	Temperature	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.340	2	0.670	9.461	< 0.025					
Between subjects	DEPTH (D)	0.347	1	0.347	4.902	0.069					
Between subjects	Z*D	0.210	2	0.105	1.484	0.299					
Between subjects	Error	0.425	6	0.071			**MANOVA**				
		Mauchly's W = 0.000; ***P*** < 0.025			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1474.499	5	294.900	5158.599	< 0.001	1.000	141972.81	5	2	< 0.001
Within subjects	T*Z	25.453	10	2.545	44.524	< 0.001	1.945	21.138	10	6	< 0.01
Within subjects	T*D	1.966	5	0.393	6.879	< 0.001	0.999	479.985	5	2	< 0.01
Within subjects	T*Z*D	2.336	10	0.234	4.087	< 0.01	1.459	1.620	10	6	0.287
Within subjects	Error	1.715	30	0.057							

	DO	ANOVA									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.963	2	0.982	2.829	0.136					
Between subjects	DEPTH (D)	0.180	1	0.180	0.519	0.498					
Between subjects	Z*D	0.003	2	0.002	0.005	0.995					
Between subjects	Error	2.082	6	0.347			**MANOVA**				
		Mauchly's W = 0.000; ***P*** < 0.025			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	59.037	5	11.807	91.569	< 0.001	0.999	550.655	5	2	< 0.01
Within subjects	T*Z	6.510	10	0.651	5.049	< 0.001	1.920	14.468	10	6	< 0.01
Within subjects	T*D	0.688	5	0.134	1.037	0.414	0.892	3.316	5	2	0.248
Within subjects	T*Z*D	0.523	10	0.052	0.406	0.933	1.141	0.797	10	6	0.643
Within subjects	Error	3.868	30	0.129							

13. Meredith River

Salinity		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	485.650	2	242.825	12.450	< 0.01					
	DEPTH (D)	1352.000	1	1352.000	69.317	< 0.001					
	Z*D	146.433	2	73.216	3.754	0.088					
	Error										
		Mauchly's W = 0.000; ***P*** < 0.001			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	3113.631	5	622.726	53.802	< 0.001	1.000	17474.357	5	2	< 0.001
	T*Z	1494.076	10	149.408	12.908	< 0.001	1.853	7.553	10	6	< 0.025
	T*D	1160.523	5	232.105	20.053	< 0.001	0.998	197.078	5	2	< 0.01
	T*Z*D	356.744	10	35.674	3.082	< 0.01	1.766	4.532	10	6	< 0.05
	Error	347.232	30	11.574							

Temperature		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	3.264	2	1.632	4.668	0.060					
	DEPTH (D)	28.501	1	28.501	81.529	< 0.001					
	Z*D	0.543	2	0.271	0.776	0.502					
	Error	2.098	6	0.350							
		Mauchly's W = 0.202; ***P*** =0.963			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1471.317	5	294.263	3606.907	< 0.001	1.000	3033.356	5	2	< 0.001
	T*Z	17.593	10	1.759	21.565	< 0.001	1.906	12.167	10	6	< 0.01
	T*D	152.190	5	30.438	373.090	< 0.001	0.998	161.889	5	2	< 0.01
	T*Z*D	5.324	10	0.532	6.526	< 0.001	1.445	1.563	10	6	0.302
	Error	2.447	30	0.082							

DO		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.280	2	0.140	3.342	0.106					
	DEPTH (D)	0.0002	1	0.0002	0.005	0.948					
	Z*D	0.019	2	0.009	0.222	0.807					
	Error	0.251	6	0.042							
		Mauchly's W = 0.085; ***P*** < 0.05			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1.246	3	0.415	13.981	< 0.001	0.836	6.818	3	4	< 0.05
	T*Z	0.254	6	0.042	1.426	0.259	0.846	1.222	6	10	0.371
	T*D	0.496	3	0.165	0.559	< 0.01	0.891	10.855	3	4	< 0.025
	T*Z*D	0.167	6	0.028	0.939	0.492	0.812	1.140	6	10	0.407
	Error	0.535	18	0.030							

14. Little Swanport

	Salinity	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	3.125	2	1.563	12.085	< 0.01					
	DEPTH (D)	0.661	1	0.661	5.114	0.064					
	Z*D	0.206	2	0.103	0.796	0.494					
	Error	0.776	6	0.129							
Within subjects		**Mauchly's W** = 0.007;	***P*** =0.168		**H-F Epsilon** = 0.783		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	98.256	3.915	25.096	202.647	< 0.001	0.999	289.307	5	2	< 0.01
	T*Z	14.490	7.830	1.850	14.942	< 0.001	1.499	1.796	10	6	0.244
	T*D	0.611	3.915	0.156	1.261	0.313	0.812	1.733	5	2	0.405
	T*Z*D	1.029	7.830	0.131	1.061	0.421	1.306	1.128	10	6	0.461
	Error	2.909	23.491	0.124							

	Temperature	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.245	2	0.623	1.673	0.265					
	DEPTH (D)	0.257	1	0.257	0.690	0.438					
	Z*D	0.227	2	0.113	0.305	0.748					
	Error	2.233	6	0.372							
Within subjects		**Mauchly's W** = 0.000;	***P*** <0.01		**H-F Epsilon** = 0.731		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	1450.652	3.657	396.629	2032.438	< 0.001	1.000	1788.489	5	2	< 0.01
	T*Z	28.873	7.315	3.947	20.226	< 0.001	1.853	7.559	10	6	< 0.025
	T*D	2.276	3.657	0.622	3.188	< 0.05	0.802	1.619	5	2	0.424
	T*Z*D	1.268	7.315	0.173	0.888	0.535	1.060	0.676	10	6	0.721
	Error	4.282	21.945	0.195							

	DO	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	12.085	2	6.043	5.116	0.083					
	DEPTH (D)	0.320	1	0.320	0.271	0.446					
	Z*D	0.286	2	0.143	0.121	0.794					
	Error	7.087	6	1.181							
Within subjects		**Mauchly's W** = 0.000;	***P*** < 0.001		**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	42.351	5	8.470	17.563	< 0.001	0.999	590.929	5	2	< 0.01
	T*Z	12.611	10	1.261	2.615	< 0.025	1.978	53.241	10	6	< 0.001
	T*D	2.280	5	0.456	0.946	0.466	0.983	23.677	5	2	< 0.05
	T*Z*D	2.142	10	0.214	0.444	0.912	0.9749	.0570	10	6	0.794
	Error	14.468	30	0.482							

15. Earlham Lagoon

	ln(salinity)	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.811	2	0.406	83.141	< 0.001					
	DEPTH (D)	0.392	1	0.392	80.412	< 0.001					
	Z*D	0.616	2	0.308	63.109	< 0.001					
	Error	0.030	6	0.005			**MANOVA**				
		Mauchly's W = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.418		**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	3.142	2.089	1.504	11.473	< 0.01	0.998	216.426	5	2	< 0.01
	T*Z	1.296	4.178	0.310	2.366	0.107	1.955	25.928	10	6	< 0.001
	T*D	0.851	2.089	0.407	3.108	0.079	0.994	69.308	5	2	< 0.025
	T*Z*D	1.361	4.178	0.326	2.485	0.095	1.016	0.619	10	6	0.760
	Error	1.643	12.534	0.131							

	Temperature	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	4.474	2	2.237	17.918	< 0.01					
	DEPTH (D)	1.201	1	1.201	9.621	< 0.025					
	Z*D	0.543	2	0.272	2.176	0.195					
	Error	0.749	6	0.125			**MANOVA**				
		Mauchly's W = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.418		**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	1259.542	5	251.908	960.770	< 0.001	1.000	2339.073	5	2	< 0.001
	T*Z	14.384	10	1.438	5.486	< 0.001	1.571	2.199	10	6	0.174
	T*D	2.018	5	0.404	1.539	0.208	0.828	1.923	5	2	0.377
	T*Z*D	5.045	10	0.505	1.924	0.081	1.229	0.957	10	6	0.548
	Error	7.866	30	0.262							

	DO	**ANOVA**									
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.804	2	0.402	1.389	0.319					
	DEPTH (D)	0.216	1	0.216	0.747	0.421					
	Z*D	0.252	2	0.126	0.435	0.666					
	Error	1.736	6	0.289			**MANOVA**				
		Mauchly's W = 0.025;	***P*** = 0.077		**H-F Epsilon** = 1.000		**Pillai's trace**				
Within subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	86.546	4	21.636	265.749	< 0.001	0.997	293.924	4	3	< 0.001
	T*Z	8.544	8	1.068	13.118	< 0.001	1.589	3.863	8	8	< 0.05
	T*D	0.526	4	0.131	1.614	0.203	0.959	17.448	4	3	< 0.025
	T*Z*D	1.006	8	0.126	1.545	0.194	1.039	1.081	8	8	0.457
	Error	1.954	24	0.081							

16. Browns River

	Salinity	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	150.273	2	75.136	3.547	0.096					
	DEPTH (D)	2473.389	1	2473.389	116.772	< 0.001					
	Z*D	746.319	2	373.159	17.617	< 0.01					
	Error	127.088	6	21.181							
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.01			**H-F Epsilon** = 0.842		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	2880.107	4.210	684.106	39.917	< 0.001	1.000	1802.487	5	2	< 0.01
	T*Z	856.616	8.420	101.735	5.936	< 0.001	1.649	2.819	10	6	0.109
	T*D	754.999	4.210	179.334	10.464	< 0.001	0.999	416.788	5	2	< 0.01
	T*Z*D	485.333	8.420	57.640	3.363	< 0.01	1.766	4.530	10	6	< 0.05
	Error	432.912	25.260	17.138							

	Temperature	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.187	2	0.593	0.538	0.610					
	DEPTH (D)	6.125	1	6.125	5.553	0.057					
	Z*D	20.006	2	10.003	9.068	< 0.025					
	Error	6.618	6	1.103							
Within subjects		**Mauchly's W** = 0.019; ***P*** =378			**H-F Epsilon** = 0.850		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	2236.974	4.250	526.296	844.053	< 0.001	1.000	903.954	5	2	< 0.01
	T*Z	17.188	8.501	2.022	3.243	< 0.025	1.481	1.710	10	6	0.264
	T*D	13.527	4.250	3.182	5.104	< 0.01	0.925	4.952	5	2	0.177
	T*Z*D	9.773	8.501	1.150	1.844	0.112	1.123	0.769	10	6	0.660
	Error	15.902	25.502	0.624							

	DO	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	4.170	2	2.085	4.203	0.072					
	DEPTH (D)	18.000	1	18.000	36.282	< 0.01					
	Z*D	7.928	2	3.964	7.990	< 0.025					
	Error	2.977	6	0.496							
Within subjects		**Mauchly's W** = 0.074; ***P*** = 0.768			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	11.286	5	2.257	4.128	< 0.01	0.890	3.225	5	2	0.253
	T*Z	11.336	10	1.134	2.073	0.060	1.558	2.114	10	6	0.186
	T*D	25.062	5	5.012	9.167	< 0.001	0.966	11.246	5	2	0.084
	T*Z*D	10.956	10	1.096	2.004	0.069	1.297	1.108	10	6	0.471
	Error	16.403	30	0.547							

17. Cloudy Bay Lagoon

	Salinity	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.954	2	0.477	32.084	< 0.01					
Between subjects	DEPTH (D)	0.001	1	0.001	0.084	0.782					
Between subjects	Z*D	0.0008	2	0.0004	0.028	0.972					
Between subjects	Error	0.089	6	0.015							
		Mauchly's W = 0.002;	***P*** < 0.05		**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	13.592	5	2.718	196.122	< 0.001	0.996	93.494	5	2	< 0.025
Within subjects	T*Z	5.251	10	0.525	37.886	< 0.001	1.976	50.032	10	6	< 0.001
Within subjects	T*D	0.018	5	0.004	0.259	0.932	0.874	2.769	5	2	0.286
Within subjects	T*Z*D	0.008	10	0.0008	0.054	1.000	0.752	0.362	10	6	0.925
Within subjects	Error	0.416	30	0.014							

	Temperature	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	14.677	2	7.338	6.799	< 0.05					
Between subjects	DEPTH (D)	1.389	1	0.0001	0.000	0.991					
Between subjects	Z*D	0.012	2	0.006	0.006	0.994					
Between subjects	Error	6.476	6	1.079							
		Mauchly's W = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.746		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	1529.776	5	305.955	1353.950	< 0.001	1.000	185433.60	5	2	< 0.001
Within subjects	T*Z	61.600	7.456	8.262	27.260	< 0.001	1.993	168.439	10	6	< 0.001
Within subjects	T*D	0.032	3.728	0.009	0.029	0.998	0.883	3.019	5	2	0.267
Within subjects	T*Z*D	0.028	7.456	0.004	0.012	1.000	0.681	0.310	10	6	0.950
Within subjects	Error	6.779	22.367	0.303							

	DO	ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	1.302	2	0.651	0.373	0.704					
Between subjects	DEPTH (D)	10.276	1	10.276	5.882	0.051					
Between subjects	Z*D	0.304	2	0.152	0.087	0.918					
Between subjects	Error	10.482	6	1.747							
		Mauchly's W = 0.000;	***P*** < 0.001		**H-F Epsilon** = 0.548		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	70.658	2.740	25.791	19.369	< 0.001	0.995	83.877	5	2	< 0.025
Within subjects	T*Z	27.031	5.479	4.933	3.705	< 0.025	1.609	2.470	10	6	0.140
Within subjects	T*D	19.309	2.740	7.048	5.293	< 0.025	0.998	193.363	5	2	< 0.01
Within subjects	T*Z*D	1.356	5.479	0.248	0.186	0.971	0.893	0.484	10	6	0.852
Within subjects	Error	21.888	16.438	1.332							

18. Catamaran River

	Salinity	**ANOVA**									
Between subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***					
	ZONE (Z)	1429.968	2	714.984	17.886	< 0.01					
	DEPTH (D)	7940.100	1	7940.100	198.633	< 0.001					
	Z*D	77.334	2	38.667	0.967	0.432					
	Error	239.843	6	39.974			**MANOVA**				
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.025			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	991.732	5	468.080	20.302	< 0.001	0.999	358.294	5	2	< 0.01
	T*Z	226.571	10	22.657	2.319	< 0.05	1.815	5.885	10	6	< 0.025
	T*D	480.359	5	96.072	9.834	< 0.001	0.998	249.242	5	2	< 0.01
	T*Z*D	452.454	10	42.245	4.631	< 0.01	1.639	2.728	10	6	0.116
	Error	293.093	30	9.770							

	Temperature	**ANOVA**									
Between subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***					
	ZONE (Z)	32.100	2	16.050	16.095	< 0.01					
	DEPTH (D)	106.580	1	106.580	106.877	< 0.001					
	Z*D	3.483	2	1.741	1.746	0.253					
	Error	5.983	6	0.997			**MANOVA**				
Within subjects		**Mauchly's W** = 0.01; ***P*** < 0.05			**H-F Epsilon** = 0.985		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	400.851	4.927	81.354	300.013	< 0.001	1.000	1815.529	5	2	< 0.01
	T*Z	10.695	9.855	1.085	4.002	< 0.01	1.898	11.139	10	6	< 0.01
	T*D	30.845	4.927	6.260	23.086	< 0.001	0.994	69.921	5	2	< 0.01
	T*Z*D	15.332	9.855	1.556	5.738	< 0.001	1.402	1.408	10	6	0.350
	Error	8.017	29.564	0.271							

	DO	**ANOVA**									
Between subjects	**Source**	**SS**	**df**	**MS**	**F**	***P***					
	ZONE (Z)	9.074	2	4.537	8.120	< 0.01					
	DEPTH (D)	63.278	3	21.093	37.750	< 0.001					
	Z*D	1.753	6	0.292	0.523	0.781					
	Error	6.705	12	0.559			**MANOVA**				
Within subjects		**Mauchly's W** = 0.096; ***P*** = 0.055			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	108.016	5	21.603	122.456	< 0.001	0.988	129.599	5	8	< 0.001
	T*Z	10.078	10	1.008	5.712	< 0.001	1.474	5.042	10	18	< 0.01
	T*D	25.302	15	1.687	9.561	< 0.001	2.013	4.082	15	30	< 0.01
	T*Z*D	12.822	30	0.427	2.423	< 0.002	1.880	1.205	30	60	0.265
	Error	10.585	60	0.176							

19. Cockle Creek

Salinity		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	11.38.989	2	569.494	28.693	< 0.01					
	DEPTH (D)	158.717	1	158.717	7.997	< 0.05					
	Z*D	13.837	2	6.918	0.349	0.719					
	Error	119.086	6	19.848							
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.01			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	4084.192	5	816.838	90.851	< 0.001	1.000	923.445	5	2	< 0.01
	T*Z	1054.716	10	105.472	11.731	< 0.001	1.715	3.603	10	6	0.065
	T*D	334.739	5	66.948	7.446	< 0.001	0.870	2.668	5	2	0.295
	T*Z*D	360.305	10	36.030	4.007	< 0.01	1.220	0.938	10	6	0.558
	Error	269.729	30	8.991							

Temperature		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	35.566	2	17.783	87.159	< 0.001					
	DEPTH (D)	0.700	1	0.700	3.432	0.113					
	Z*D	0.167	2	0.083	0.409	0.681					
	Error	1.224	6	0.204							
Within subjects		**Mauchly's W** = 0.001; ***P*** < 0.05			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	1627.873	5	325.575	2750.689	< 0.001	1.000	58061.919	5	2	< 0.001
	T*Z	30.058	10	3.006	25.395	< 0.001	1.942	20.102	10	6	< 0.01
	T*D	1.661	5	0.332	2.806	< 0.05	0.720	1.027	5	2	0.561
	T*Z*D	1.870	10	0.187	1.580	0.161	0.974	0.569	10	6	0.794
	Error	3.551	30	0.118							

DO		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	4.723	2	2.362	3.838	0.084					
	DEPTH (D)	49.833	1	49.833	80.975	< 0.001					
	Z*D	0.681	2	0.341	0.553	0.602					
	Error	3.693	6	0.615							
Within subjects		**Mauchly's W** = 0.052; ***P*** =0.669			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	47.015	5	9.403	50.712	< 0.001	0.994	68.811	5	2	< 0.025
	T*Z	3.623	10	0.362	1.954	0.076	1.526	1.929	10	6	0.218
	T*D	11.482	5	2.296	12.385	< 0.001	0.961	9.809	5	2	0.095
	T*Z*D	5.866	10	0.587	3.163	< 0.01	1.510	1.849	10	6	0.233
	Error	5.563	30	0.185							

20. Pieman River

Salinity		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	46.252	2	23.126	15.176	< 0.01					
	DEPTH (D)	3045.938	1	3045.938	1998.865	< 0.001					
	Z*D	67.392	2	33.696	22.113	< 0.01					
	Error	9.143	6	1.524							
		Mauchly's W = 0.000; ***P*** < 0.001			**H-F Epsilon** = 0.519		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	2854.069	2.076	1374.609	71.076	< 0.001	1.000	8981.281	4	3	< 0.001
	T*Z	86.633	4.153	20.863	1.079	0.410	1.948	37.136	8	8	< 0.001
	T*D	2441.158	2.076	1175.738	60.793	< 0.001	1.000	8253.755	4	3	< 0.001
	T*Z*D	112.200	4.153	27.019	1.397	0.291	1.928	26.587	8	8	< 0.001
	Error	240.932	12.458	19.340							

Temperature		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	2.847	2	1.423	5.882	< 0.05					
	DEPTH (D)	5.521	1	5.521	22.813	< 0.01					
	Z*D	0.96	2	0.498	2.059	0.209					
	Error										
		Mauchly's W = 0.062; ***P*** = 0.226			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	415.692	4	103.923	556.979	< 0.001	1.000	1523.418	4	3	< 0.001
	T*Z	2.926	8	0.366	1.960	0.097	1.361	2.129	8	8	0.153
	T*D	25.158	4	6.289	33.708	< 0.001	0.964	19.890	4	3	< 0.025
	T*Z*D	5.410	8	0.676	3.625	< 0.01	5.231	1.308	8	8	0.258
	Error	4.478	24	0.187							

DO		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	4.732	2	2.366	61.455	< 0.001					
	DEPTH (D)	30.388	1	30.388	789.303	< 0.001					
	Z*D	2.321	2	1.161	30.147	< 0.01					
	Error	0.231	6	0.039							
		Mauchly's W = 0.011; ***P*** < 0.05			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
Within subjects	TIME (T)	37.449	4	9.362	26.547	< 0.001	0.986	54.448	4	3	< 0.01
	T*Z	7.490	8	0.936	2.655	< 0.05	1.553	3.476	8	8	< 0.05
	T*D	22.789	4	5.697	16.155	< 0.001	0.975	29.713	4	3	< 0.025
	T*Z*D	2.924	8	0.365	1.036	0.437	1.013	1.027	8	8	0.486
	Error	8.464	24	0.353							

21. Nelson Bay River

ln (sal. + 0.1)

	Source	SS	df	MS	F	*P*					
		ANOVA									
Between subjects	ZONE (Z)	3.503	1	3.503	3.236	0.146					
	DEPTH (D)	0.029	1	0.029	0.026	0.879					
	Z*D	0.023	1	0.023	0.021	0.892					
	Error	4.330	4	1.082			MANOVA				
		Mauchly's W = 0.000; *P* < 0.001			H-F Epsilon = 0.507		Pillai's trace				
	Source	SS	df	MS	F	*P*	Value	F	Hypo. df	Error df	*P*
Within subjects	TIME (T)	117.599	2.030	57.939	24.313	< 0.001	1.000	1927.318	3	2	< 0.01
	T*Z	8.137	2.030	4.009	1.682	0.245	0.999	804.147	3	2	< 0.01
	T*D	0.075	2.030	0.037	0.016	0.985	0.681	1.425	3	2	0.438
	T*Z*D	0.078	2.030	0.038	0.016	0.985	0.746	1.958	3	2	0.356
	Error	19.348	8.119	2.383							

Temperature

	Source	SS	df	MS	F	*P*					
		ANOVA									
Between subjects	ZONE (Z)	1.332	1	1.332	21.930	< 0.01					
	DEPTH (D)	0.006	1	0.006	0.103	0.764					
	Z*D	0.023	1	0.023	0.037	0.857					
	Error						MANOVA				
		Mauchly's W = 0.000; *P* < 0.05			H-F Epsilon = 0.741		Pillai's trace				
	Source	SS	df	MS	F	*P*	Value	F	Hypo. df	Error df	*P*
Within subjects	TIME (T)	259.160	2.965	87.400	227.234	< 0.001	1.000	2503.854	4	1	< 0.025
	T*Z	1.799	2.965	0.607	1.577	0.247	0.991	27.836	4	1	0.141
	T*D	1.105	2.965	0.373	0.969	0.439	0.966	7.148	4	1	0.273
	T*Z*D	0.054	2.965	0.018	0.047	0.985	0.667	0.500	4	1	0.770
	Error	4.562	11.861	0.385							

DO

	Source	SS	df	MS	F	*P*					
		ANOVA									
Between subjects	ZONE (Z)	7.125	1	7.125	14.295	< 0.025					
	DEPTH (D)	4.133	1	4.133	8.292	< 0.05					
	Z*D	3.578	1	3.578	7.178	0.055					
	Error	1.994	4	0.498			MANOVA				
		Mauchly's W = 0.002; *P* < 0.01			H-F Epsilon = 0.797		Pillai's trace				
	Source	SS	df	MS	F	*P*	Value	F	Hypo. df	Error df	*P*
Within subjects	TIME (T)	114.711	2.392	47.949	107.931	< 0.001	1.000	2303.385	3	2	< 0.001
	T*Z	11.578	2.392	4.480	10.894	< 0.01	0.989	57.947	3	2	< 0.025
	T*D	11.026	2.392	4.609	10.374	< 0.01	0.909	6.652	3	2	0.133
	T*Z*D	10.471	2.392	4.377	9.852	< 0.01	0.792	2.540	3	2	0.295
	Error	4.251	9.569	0.444							

22. Arthur River

Salinity		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	95.329	2	47.664	7.368	< 0.025					
	DEPTH (D)	2823.576	1	2823.576	436.455	< 0.001					
	Z*D	53.497	2	26.749	4.135	0.074					
	Error	38.816	6	6.469							
Within subjects		**Mauchly's W** = 0.000; ***P*** < 0.001			**H-F Epsilon** = 0.777		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	2634.048	3.109	847.148	170.647	< 0.001	1.000	2006.362	4	3	< 0.001
	T*Z	76.619	6.219	12.803	2.579	0.053	1.538	3.333	8	8	0.054
	T*D	1891.949	3.109	608.479	122.570	< 0.001	0.999	1280.638	4	3	< 0.001
	T*Z*D	82.018	6.219	13.189	2.657	< 0.05	1.539	3.334	8	8	0.054
	Error	92.614	18.656	4.964							

Temperature		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	0.476	2	0.238	1.025	0.414					
	DEPTH (D)	0.216	1	0.216	0.930	0.372					
	Z*D	0.793	2	0.396	1.707	0.259					
	Error	1.394	6	0.232							
Within subjects		**Mauchly's W** = 0.006; ***P*** < 0.025			**H-F Epsilon** = 0.924		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	678.368	3.695	183.591	580.132	< 0.001	1.000	1601.576	4	3	< 0.001
	T*Z	6.270	7.390	0.848	2.681	< 0.05	1.054	1.114	8	8	0.441
	T*D	50.496	3.695	13.666	43.183	< 0.001	0.988	63.530	4	3	< 0.01
	T*Z*D	2.030	7.390	0.275	0.868	0.551	1.293	1.829	8	8	0.206
	Error	7.016	22.170	0.316							

DO		ANOVA					MANOVA				
	Source	**SS**	**df**	**MS**	**F**	***P***					
Between subjects	ZONE (Z)	3.796	2	1.898	3.438	0.101					
	DEPTH (D)	61.004	1	61.004	110.481	< 0.001					
	Z*D	7.104	2	3.552	6.433	< 0.05					
	Error	3.313	6	0.552							
Within subjects		**Mauchly's W** = 0.047; ***P*** =0.165			**H-F Epsilon** = 1.000		**Pillai's trace**				
	Source	**SS**	**df**	**MS**	**F**	***P***	**Value**	**F**	**Hypo. df**	**Error df**	***P***
	TIME (T)	424.194	4	106.049	194.704	< 0.001	0.997	271.806	4	3	< 0.001
	T*Z	54.579	8	6.822	12.526	< 0.001	1.505	3.043	8	8	0.068
	T*D	48.775	4	12.194	22.388	< 0.001	0.982	39.835	4	3	< 0.01
	T*Z*D	19.304	8	2.413	4.430	< 0.01	1.001	1.001	8	8	0.499
	Error	13.072	24	0.545							

Appendix 4. Component matrices for Principal Component Analysis of water quality parameters from surface waters (absolute coefficient values ≥ 0.7 in bold, absolute values < 0.6 not shown).

Duck Bay

Component	1	2	3
% of variance	60.2	14.3	12.7
Cumulative %	60.2	74.5	87.3
Parameter			
Turbidity	**.981**		
Volatile SS	**.959**		
Total SS	**.911**		
NO_x-N	**.875**		
Fixed SS	**.874**		
Chlorophyll *a*	**.852**		
Salinity	**-.826**		
PO_4-P	.649		
SiO_4-Si		**.770**	
Dissolved O_2		-.648	
Temperature		.628	.602

East Inlet

Component	1	2	3	4
% of variance	43.3	20.4	13.8	9.9
Cumulative %	43.3	63.7	77.5	87.4
Parameter				
Fixed SS	**.836**			
Total SS	**.827**			
PO_4-P	**.776**			
Turbidity	**.736**			
Dissolved O_2	**.733**			
Volatile SS	**.703**	.615		
NO_x-N	.606			
Chlorophyll *a*	-.623	.631		
Salinity			**.851**	
Temperature				
SiO_4-Si				.678

Black River

Component	1	2
% of variance	43.1	29.2
Cumulative %	43.1	72.3
Parameter		
Salinity	**.933**	
Turbidity	**-.903**	
NO_x-N	**-.839**	
SiO_4-Si	**.837**	
Temperature	**.785**	
Chlorophyll *a*		
Total SS		**.908**
Fixed SS		**.891**
Volatile SS		**.786**
PO_4-P		**.727**

Don River

Component	1	2
% of variance	48.7	36.7
Cumulative %	48.7	85.4
Parameter		
Volatile SS	**.947**	
Total SS	**.923**	
Turbidity	**.903**	
Fixed SS	**.901**	
Chlorophyll *a*	**.873**	
PO_4-P	.645	
SiO_4-Si		**.941**
NO_x-N		**.895**
Temperature		**-.891**
Salinity		**-.865**

Mersey River

Component	1	2
% of variance	52.2	31.7
Cumulative %	52.2	82.5
Parameter		
Volatile SS	**.953**	
Turbidity	**.911**	
Total SS	**.811**	
Fixed SS	**.848**	
Salinity	**-.716**	
SiO_4-Si	.670	-.655
Chlorophyll *a*	.635	.607
PO_4-P		
Temperature		**.916**
NO_x-N		**-.800**

Port Sorell

Component	1	2
% of variance	62.6	19.5
Cumulative %	62.5	82.0
Parameter		
Turbidity	**.984**	
Total SS	**.971**	
Fixed SS	**.962**	
Volatile SS	**.896**	
Salinity	**-.883**	
SiO_4-Si	**.847**	
PO_4-P		
Temperature		**.844**
Chlorophyll *a*	.642	**.704**
NO_x-N	.648	-.692

Boobyalla Inlet

Component	1	2	3
% of variance	41.9	26.1	17.7
Cumulative %	41.9	68.0	85.7
Parameter			
Turbidity	**.943**		
Temperature	**-.853**		
SiO_4-Si	**-.829**		
Fixed SS	.673	.665	
PO_4-P			
Total SS	.634	.692	
Salinity	-.607	.680	
NO_x-N	.622	-.646	
Volatile SS		.610	
Chlorophyll *a*			**.837**
Dissolved O_2			.686

Little Musselroe River

Component	1	2	3
% of variance	38.6	26.2	19.5
Cumulative %	38.6	64.8	84.3
Parameter			
Turbidity	**.941**		
Volatile SS	**.841**		
Total SS	**.727**		
Chlorophyll *a*	.689		
Fixed SS	.656	.601	
NO_x-N		**-.779**	
Salinity		**.707**	
SiO_4-Si		-.657	
Dissolved O_2			**.853**
Temperature			.637
PO_4-P			.625

Ansons Bay

Component	1	2	3
% of variance	33.0	23.2	13.2
Cumulative %	33.0	56.2	69.4
Parameter			
Volatile SS	**.807**		
Total SS	**.751**	-.620	
Turbidity	**.731**		
Fixed SS	.680	-.636	
Chlorophyll *a*	.636		
Salinity	-.632		
SiO_4-Si	.626		
NO_x-N		.693	
Dissolved O_2			**.759**
Temperature			-.670
PO_4-P			

Grants Lagoon

Component	1	2	3	4
% of variance	32.2	28.1	14.2	10.6
Cumulative %	32.2	60.3	74.5	85.1
Parameter				
SiO_4-Si	**.867**			
Salinity	**-.750**			
Temperature	**.734**			
Chlorophyll *a*	**.724**			
Dissolved O_2	-.677			
Turbidity	.625			
Total SS		**.974**		
Fixed SS		**.970**		
Volatile SS		**.830**		
NO_x-N			**.772**	
PO_4-P				**.830**

Douglas River

Component	1	2	3
% of variance	41.9	24.7	11.6
Cumulative %	41.9	66.6	78.2
Parameter			
SiO_4-Si	**-947**		
Total SS	**.841**		
Volatile SS	**.817**		
Fixed SS	**.802**		
Chlorophyll *a*	**.766**		
NO_x-N	**-.747**		
Dissolved O_2			
Temperature		**.757**	
PO_4-P		**.750**	
Turbidity		**-.744**	
Salinity		.673	

Great Swanport

Component	1	2	3	4
% of variance	34.0	22.0	16.6	10.5
Cumulative %	34.0	56.0	72.6	83.1
Parameter				
Volatile SS	**.867**			
Total SS	**.864**			
Fixed SS	**.813**			
Turbidity	**.793**			
Temperature		**.809**		
NO_x-N		**.795**		
Salinity		-.677		
SiO_4-Si				
PO_4-P				
Dissolved O_2				
Chlorophyll *a*				-.699

Meredith River

Component	1	2
% of variance	44.5	29.4
Cumulative %	44.5	73.9
Parameter		
Volatile SS	**.898**	
Chlorophyll *a*	**.854**	
Total SS	**.830**	
Fixed SS	**.755**	
PO_4-P	**.701**	
SiO_4-Si	-.614	
Salinity		**-.785**
Turbidity		**.752**
NO_x-N		.695
Temperature		

Little Swanport

Component	1	2	3
% of variance	35.6	22.1	19.3
Cumulative %	35.6	57.6	77.0
Parameter			
Volatile SS	**.912**		
Total SS	**.788**		
Fixed SS	**.747**	.629	
SiO_4-Si	.662		
Turbidity	.651		
NO_x-N		**.705**	
PO_4-P		.694	
Temperature			
Dissolved O_2			**-.742**
Chlorophyll *a*			**.704**
Salinity	-.604		.633

Earlham Lagoon

Component	1	2	3
% of variance	37.5	23.4	17.0
Cumulative %	37.5	60.8	77.9
Parameter			
Fixed SS	**.868**		
Total SS	**.867**		
SiO_4-Si	**.860**		
Volatile SS	**.736**		
Turbidity	.628		
NO_x-N			
Dissolved O_2		**.779**	
Temperature		-.683	
Salinity			
PO_4-P			**.735**
Chlorophyll *a*			-.630

Browns River

Component	1	2
% of variance	48.4	24.4
Cumulative %	48.4	72.8
Parameter		
Turbidity	**.859**	
Salinity	**-.854**	
Fixed SS	**.803**	
Total SS	**.800**	
NO_x-N	**.764**	
Temperature	**-.710**	
SiO_4-Si	.639	
PO_4-P		
Dissolved O_2		
Chlorophyll *a*		**.840**
Volatile SS	.603	.713

Cloudy Bay

Component	1	2	3	4	5
% of variance	28.7	19.1	16.7	12.2	9.5
Cumulative %	28.7	47.8	64.5	76.7	86.3
Parameter					
Total SS	**.911**				
Fixed SS	**.880**				
Volatile SS	**.805**				
Salinity					
Chlorophyll *a*		**.847**			
Temperature		**-.738**			
NO_x-N			**-737**		
Turbidity			.679		
Dissolved O_2			.646		
PO_4-P					
SiO_4-Si					-.685

Catamaran River

Component	1	2	3	4
% of variance	44.4	20.1	15.2	10.2
Cumulative %	44.4	64.5	79.7	89.9
Parameter				
Salinity	**.921**			
Fixed SS	**.811**			
Temperature	**.796**			
Total SS	**.743**	.611		
PO_4-P	**.730**			
Turbidity	**-.730**			
Dissolved O_2	**-.725**			
Chlorophyll *a*				
Volatile SS		**.796**		
SiO_4-Si			**.890**	
NO_x-N				.644

Cockle Creek

Component	1	2	3
% of variance	40.4	21.8	17.2
Cumulative %	40.4	62.2	79.4
Parameter			
Salinity	**.920**		
Temperature	**.829**		
SiO_4-Si	**-.724**		
Turbidity	-.693		
Dissolved O_2	-.675		
Volatile SS		**.820**	
Total SS	.636	**.745**	
Fixed SS	.663	.684	
NO_x-N			**.765**
PO_4-P			**.751**
Chlorophyll *a*			-.699

Pieman River

Component	1	2	3
% of variance	40.3	26.8	11.3
Cumulative %	40.3	67.1	78.4
Parameter			
Total SS	**.953**		
Fixed SS	**.908**		
Volatile SS	**.899**		
Turbidity	**.883**		
Salinity	.636		
Temperature		**.918**	
Dissolved O_2		-.697	
SiO_4-Si		.638	
PO_4-P		-.617	
NO_x-N			.679
Chlorophyll *a*			

Nelson Bay River

Component	1	2	3
% of variance	55.0	20.5	11.6
Cumulative %	55.0	75.5	87.1
Parameter			
Turbidity	**.957**		
Salinity	**-.883**		
SiO_4-Si	**-.876**		
Chlorophyll *a*	**-.875**		
NO_x-N	**.848**		
Volatile SS	**.803**		
PO_4-P	-.624		
Fixed SS		**.915**	
Total SS		.679	
Temperature		-.676	

Arthur River

Component	1	2
% of variance	56.5	20.7
Cumulative %	56.5	77.2
Parameter		
SiO_4- Si	**-.962**	
Turbidity	**.899**	
Salinity	**-.868**	
Total SS	**.802**	
Volatile SS	**.773**	
NO_x-N	**.760**	
PO_4-P	**.757**	
Dissolved O_2	**.730**	-.626
Fixed SS	.656	
Chlorophyll *a*		
Temperature		**.792**